Carbon Capture Journal

CCUS in the U.S.

Decarbonising the U.S. energy system by accelerating innovation

Carbon Capture Coalition policy blueprint to accelerate CCS

ExxonMobil to invest $3 billion in low carbon

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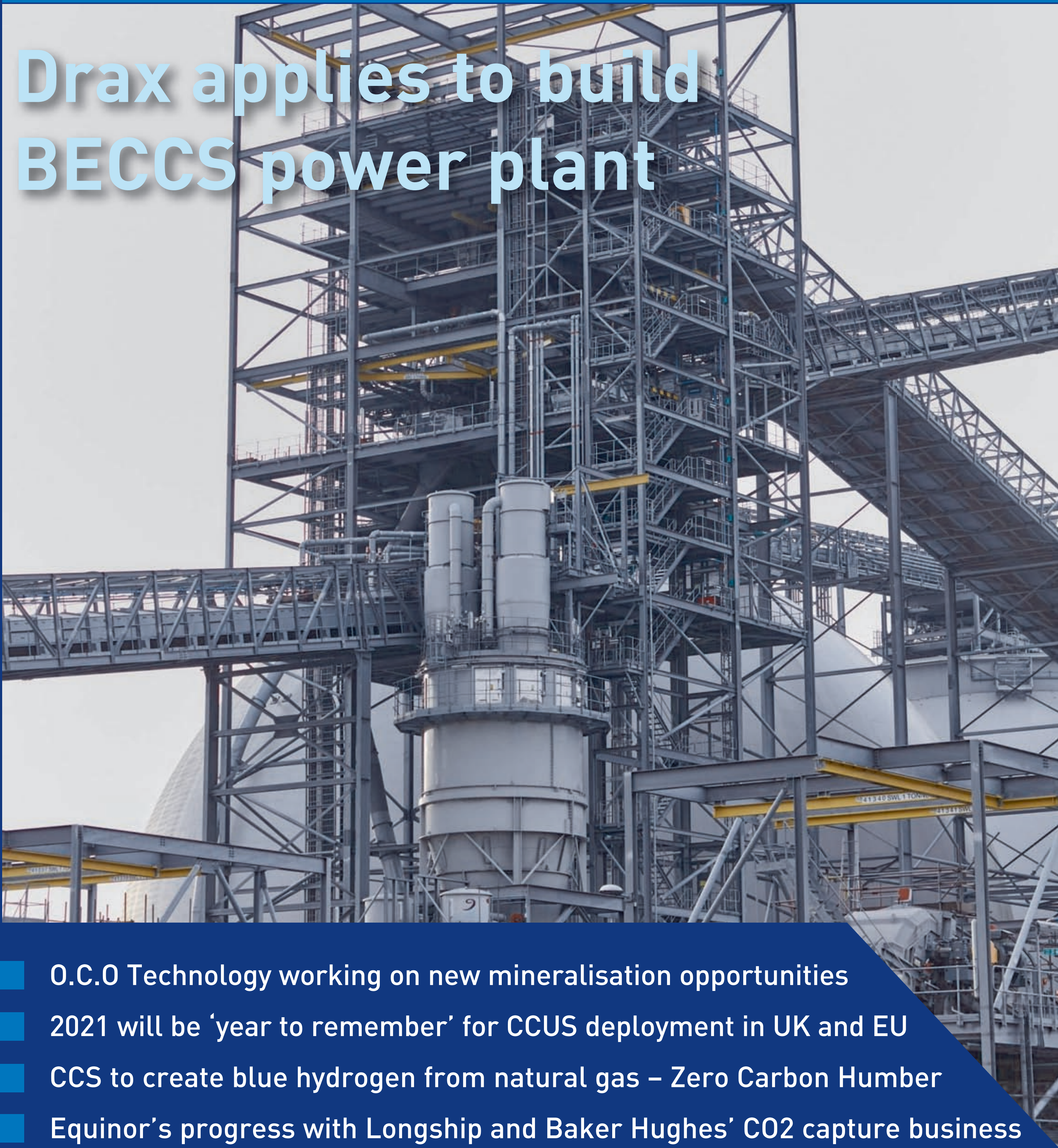

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Carbon Capture Coalition releases policy blueprint to accelerate CCS

The Federal Policy Blueprint outlines a comprehensive and ambitious federal policy agenda to realize economywide carbon capture deployment in the U.S. and serves as a roadmap for Coalition engagement with federal policymakers.

The Carbon Capture Coalition has released a national policy blueprint outlining an expanded, comprehensive federal policy portfolio to promote economywide deployment of carbon capture technologies for consideration by the administration and the 117th Congress.

The blueprint represents a consensus of the Coalition's more than 80 energy, industrial and technology companies, labor unions, and conservation, environmental, and clean energy organizations. It highlights an extensive suite of near-term recommendations for policymakers to adopt to maximize the impact of the 45Q tax credit, facilitate the buildout of CO2 transport and storage capacity, and increase federal investment in carbon management technologies, among others.

"Our Coalition works together in a bipartisan, consensus-based fashion to achieve a common goal: economywide deployment of carbon capture, removal, transport, utilization and storage to meet midcentury climate goals, foster domestic energy and industrial production, and provide jobs that consistently pay above prevailing wages," said Great Plains Institute Vice President and Coalition Staff Director Brad Crabtree, who noted that this new set of policy recommendations expands upon the Coalition's 2019 Federal Policy Blueprint released during the 116th Congress.

"This 2021 Federal Policy Blueprint outlines a comprehensive, ambitious and bipartisan federal policy agenda for carbon capture deployment and serves as a roadmap for Coalition engagement with federal policymakers," Crabtree said.

Released during a public virtual event for Coalition members and carbon capture stakeholders across the country, the blueprint provides specific recommendations for federal action arranged in four complementary areas: investment certainty, project finance and feasibility; technology deployment and cost reductions; storage infrastructure and market development; as well as jobs, economic development and affected communities.

In addition to retaining several policy measures previously endorsed by the Coalition, the blueprint highlights new priorities aimed at driving commercialization of carbon capture in key sectors, such as heavy industry, electric power generation and direct air capture that are critical to achieving net-zero emissions, but which face significantly higher costs of deployment.

New policy recommendations put forth by the Coalition to close these cost gaps include enhanced 45Q credit values for higher cost sectors, an optional electricity production tax credit alternative to 45Q to increase the feasibility of carbon capture in natural gas power generation, and a reformed and expanded investment tax credit for carbon capture, carbon utilization and direct air capture projects.

The updated blueprint also places greater emphasis on the important role the federal government must play in helping to finance the buildout of the CO2 transport and geologic storage infrastructure required to reach net-zero emissions.

The Coalition's top infrastructure priority is the enactment of the bipartisan Storing CO2 and Lowering Emissions Act (SCALE Act), which would provide low-interest federal loans and grants for large capacity CO2 transport infrastructure and funding for the development of large-scale commercial saline geologic storage sites to serve as regional storage hubs.

Additionally, the Coalition urges Congress to fulfill its commitment to increase federal investment in carbon management by fully funding the robust authorization levels for research, development & demonstration programs for carbon capture, removal, utilization and geologic storage included in the bipartisan fiscal year 2021 Omnibus legislation that passed in December.

These recommendations aim to build upon existing federal policy, notably the 45Q tax credit, to greatly expand the number and diversity of projects under development and increase overall emissions reductions, while spurring job creation and private investment at a time when our nation seeks to recover economically from the COVID-19 pandemic.

Crabtree noted that the blueprint is well-timed with a new administration and the start of a new Congress.

"Momentum for carbon capture is building in the U.S., as evidenced by the groundbreaking bipartisan provisions enacted in the year-end omnibus spending package and the more than 30 carbon capture, direct air capture and geologic storage projects publicly announced in response to the 45Q tax credit."

"We must now continue to scale federal investments and policy ambition for carbon capture — the Coalition will be calling on Congress and the administration to include key priorities from the blueprint in broader COVID-19, infrastructure and climate legislation this year," Crabtree concluded.

The Carbon Capture Coalition is a nonpartisan collaboration of more than 80 businesses and organizations building federal policy support for economy-wide deployment of carbon capture, transport, use, removal and storage and convened by the Great Plains Institute, Coalition.

More information

www.carboncapturecoalition.org
www.betterenergy.org

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Front cover:

Biomass domes and conveyor system at Drax Power Station, North Yorkshire (Image courtesy of Drax) (pg. 16)

Back cover: Marcel Suhner at Sulzer looks at what to consider when selecting separation technologies for carbon sequestration for large scale applications in power plants and manufacturing facilities - image shows a gas turbine electrical power plant (pg. 22)

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How to decarbonize the U.S. energy system by accelerating innovation

A report by the National Academies of Sciences, Engineering, and Medicine (NASEM) issues a clarion call for more clean energy innovation, finding that "deep decarbonization is technically feasible, but proactive innovation is essential."

Achieving net-zero carbon emissions in the U.S. by 2050 is feasible and would not only help address climate change but also build a more competitive economy, increase high-quality jobs, and help address social injustice in the energy system, says a new report from the National Academies of Sciences, Engineering, and Medicine.

The committee that wrote the report emphasized that immediate action and proactive innovation are required and recommended a portfolio of near-term policies to ensure equitable access to benefits generated as a result of this transition, mitigate harms to vulnerable populations and engage public participation in decision-making, and revitalize the U.S. manufacturing sector.

CO2 is the primary driver of climate change. Accelerating Decarbonization of the U.S. Energy System says most near-term reductions in emissions would come from the electricity sector, electrification of vehicles, and home heating. Other industries such as aviation, shipping, steel, cement, and chemicals manufacturing will need further innovation to achieve cost-effective decarbonization.

The report, the first of two, presents a technical blueprint and policy road map for the next 10 years of the nation's transition to net-zero carbon emissions. Among other actions, the report calls on Congress and the executive branch to set an economy-wide emissions budget for the next several decades.

Starting with a price of $40 per ton of carbon, increased annually by 5 percent, this budget will create an economic incentive to reduce carbon emissions and unlock innovation in every corner of the energy economy, according to the report.

To guide policymakers through the transition, the report lays out nine technological and socio-economic goals to reach by 2030:

Proactive Innovation Is Essential

Information Technology and Innovation Foundation (ITIF) Senior Policy Analyst Colin Cunliff, who served on the committee that produced the report, highlighted key actions recommended by the report in a blog post.

Bringing new energy technologies to market can take 20-70 years from the first prototype, and driving maturation and cost declines for nascent industries proceeds over a decade or longer time scales, he says. Therefore, proactive RD&D and market creation efforts are needed in the 2020s to develop, improve, and scale-up nascent, low-carbon energy technologies, including:

• Clean firm electricity resources, including advanced nuclear; carbon capture and storage (CCS); enhanced geothermal systems; hydrogen combustion turbines and fuel cells.

• Processes for using low-carbon energy carriers such as hydrogen, both as reductants (e.g. for steel) and as precursors and products (e.g. ammonia, methanol, ethylene); process heat solutions across all temperature ranges; and advanced electrolyzers

• Batteries and other energy storage technologies for both vehicle and grid applications

• Low- and Zero-carbon fuels, including hydrogen production from electrolysis, biomass gasification, and methane reforming with CCS, as well as synthetic drop-in fuels and advanced biofuels

• Carbon capture, utilization, and storage (CCUS) for applications across the industry and power sectors

The committee recommends a suite of policies to directly enhance and expand the energy innovation toolkit.

Producing carbon-free electricity. The nation needs to double the share of electricity generated by non-carbon-emitting sources to at least 75 percent. This will require deploying record-setting levels of solar and wind technologies, scaling back coal and some gas-fired power plants, and preserving operating nuclear plants and hydroelectric facilities where possible.

Electrifying energy services in transportation, buildings, and industry. Fifty percent of new vehicle sales across all classes should be zero-emission vehicles. The U.S. should replace at least 20 percent of fossil fuel furnaces with electric heat pumps in buildings and initiate policies so that new construction is all electric except in the coldest climate zones. Where industrial processes cannot be fully electrified, they should begin the transition to low-carbon heat sources.

Investing in energy efficiency and productivity. Total energy use by new buildings should be reduced by 50 percent. In existing buildings, energy used for space conditioning and plug-in devices should be lowered every year to achieve a 30 percent reduction by

2030. Goals for industrial energy productivity (dollars of economic output per energy consumed) should increase each year.

Planning, permitting, and building critical infrastructure. The nation should increase overall electrical transmission capacity by approximately 40 percent in order to better distribute high-quality and low-cost wind and solar power from where it is generated to where it can be used across the country.

The U.S. should also accelerate the build-out of the electric vehicle recharging network and initiate a national CO2 capture, transport, and disposal network to ensure that CO2 can be removed from point sources across the country.

Expanding the innovation toolkit. The nation should triple the U.S. Department of Energy's investment in clean energy research, development, and demonstration in order to provide new technology options, reduce costs for existing options, and better understand how to manage a socially just energy transition.

Strengthening the U.S. economy. Studies estimate that the transition to a net-zero emissions economy could increase net employment by 1 million to 2 million jobs over the next decade and provide a net increase in jobs paying higher wages than the national average. Establishing a federal "Green Bank" to finance low- or zero-carbon technologies, business creation, and infrastructure would ensure industrial competitiveness.

Promoting equity and inclusion. Policies should work to eliminate inequities in the current energy system that disadvantage historically marginalized and low-income populations. For example, the U.S. should increase funds for low-income households for home electrification and weatherization and for broadband Internet access for low-income and rural areas, and increase electrification of tribal lands.

Supporting communities, businesses, and workers. Any fundamental technological and economic transition creates new opportunities as well as job losses and other associated impacts in legacy industries. Policies should promote fair access to new long-term employment opportunities and provide financial and other support to communities that might otherwise be harmed by the transition. Educational programs should be created to train the net-zero workforce, including a "GI Bill" style program.

The report also recommends the creation of a two-year National Transition Task Force to assess the long-term implications of the transition for workers and communities, a White House Federal Office of Equitable Energy Transitions to act on that task force's recommendations, and a new independent National Transition Corporation to provide support and opportunities for displaced workers and affected communities.

Maximizing cost-effectiveness. A cost-effective strategy (balanced by equity considerations) will reduce carbon emissions, strengthen the U.S. economy, and avoid undue burdens on American households and businesses during the transition to a net-zero emissions economy. If the country can avoid spending more than necessary to achieve net-zero emissions, additional resources will be available to meet other societal needs.

"Because of dramatic decreases in the costs of renewable electricity and batteries, the U.S. can now — during the 2020s — make strides toward achieving a net-zero emitting energy system at a cost lower than investing in reduced air pollution alone," said Stephen Pacala, the Frederick D. Petrie Professor of Ecology and Evolutionary Biology at Princeton University and chair of the committee that wrote the report.

"Because the energy system impacts so many aspects of society, a transition to net-zero will have profound implications well beyond climate and energy — and it is paramount that we maintain a strong social contract to ensure this transition benefits all communities."

The report also outlines policies targeting specific energy supply and distribution goals to allow the electric power system to depend upon flexible demand enabled by pricing reforms and infrastructure upgrades.

In addition, to ensure markets for clean energy work for all, the U.S. should establish manufacturing standards for net-zero appliances, require recipients of federal funds and their contractors to meet labor standards, and enforce Buy America/Buy American provisions for federally funded activities.

"As efforts accelerate to confront the climate crisis, this report can guide decision-makers considering policies to get us to net-zero emissions that are supported by science across many disciplines," said Marcia McNutt, president of the National Academy of Sciences. "This report is one of many studies and events planned at the National Academies this year to help leaders map evidence-based and equitable paths to solving the climate change challenge confronting our planet."

Information Technology and Innovation Foundation (ITIF) Senior Policy Analyst Colin Cunliff commented:

"Transitioning to an energy system with net-zero emissions is critical for mitigating climate change, protecting human health, and revitalizing the economy, but it can't happen unless we accelerate clean energy innovation."

"The problem is that net-zero alternatives haven't yet been commercialized for some sectors that are particularly hard to abate—from aviation and shipping to steel, cement, and chemicals manufacturing. Meanwhile, many of the clean technologies that have been commercialized so far, such as electric vehicles, are still more expensive than the dirty technologies they would replace. The solution to both of those problems is to accelerate clean energy innovation."

"That's why the National Academies' new report is so important. It issues a clarion call for more clean energy innovation, finding that "deep decarbonization is technically feasible, but proactive innovation is essential." It also recognizes that innovation won't happen without an assertive federal policy that involves much more than just basic research funding."

"As the report says, achieving deep decarbonization requires "both proactive public investment in research, development, and demonstration (RD&D) and the creation of markets to hasten early adoption and ignite private sector innovation and competition." All of these policies must work together if the United States is to reap the full benefits of its investments and regain global leadership and competitiveness in clean energy."

Cunliff provides further analytical context in his blog post as he summarizes the NASEM report's key findings and recommendations.

More information

The full report is available at:
www.nationalacademies.org

Read Colin Cunliff's ITIF blog post:
www.itif.org

ExxonMobil Low Carbon Solutions to invest $3 billion

ExxonMobil has created a new business which will initially focus on carbon capture and storage commercialisation. ExxonMobil Low Carbon Solutions is advancing plans for more than 20 new carbon capture and storage opportunities around the world to enable large-scale emission reductions.

ExxonMobil plans to invest $3 billion on lower emission energy solutions through 2025.

The company has an equity share in about one-fifth of global CO2 capture capacity and has captured approximately 40 percent of all the captured anthropogenic CO2 in the world.

ExxonMobil Low Carbon Solutions will also use ExxonMobil's significant experience in the production of hydrogen which, when coupled with CCS, is likely to play a critical role in a lower-carbon energy system. Other technology focus areas in ExxonMobil's low carbon portfolio will be added in the future as they mature to commercialization.

"With our demonstrated leadership in carbon capture and emissions reduction technologies, ExxonMobil is committed to meeting the demand for affordable energy while reducing emissions and managing the risks of climate change," said Darren Woods, chairman and chief executive officer.

"We are focused on proprietary projects and commercial partnerships that will have a demonstrably positive impact on our own emissions as well as those from the industrial, power generation and commercial transportation sectors, which together account for 80 percent of global CO2 emissions. We have the expertise that can help bring technologies to market and make a meaningful difference."

The business will seek to develop partnerships and collaborations on a wide range of technologies, and be responsible for marketing of emission-reduction credits created through the business's sequestration projects.

New CCS projects and partnerships under evaluation include:

• U.S. Gulf Coast – ExxonMobil is assessing multiple CCS projects along the U.S. Gulf Coast that have the potential to collect millions of tonnes of CO2 from industrial sources for storage in onshore and offshore geologic formations. Included in these projects is a CCS hub concept in Southeast Texas.

• Wyoming, USA – ExxonMobil has progressed permitting for the expansion of its La Barge CCS facilities, which could enable an additional one million tonnes of CO2 per year to be captured. Existing facilities currently capture approximately 7 million tonnes per year, which is the largest amount of CO2 captured by any industrial facility in the world.

• Netherlands – ExxonMobil has executed a joint development agreement to advance its interest in the Port of Rotterdam CO2 Transportation Hub and Offshore Storage project, known as Porthos. The Porthos project aims to collect CO2 emissions from industrial sources and transport them by pipeline to depleted North Sea offshore gas fields.

Porthos and its potential customers have applied for EU and national support mechanisms. ExxonMobil also participates in the H-Vision study into large-scale production of low-carbon hydrogen in Rotterdam.

• Belgium – ExxonMobil is participating in the multi-stakeholder CCS project at the Port of Antwerp, Europe's largest integrated energy and chemicals cluster. The project, which would collect CO2 emissions from industrial sources for storage, recently applied for support from the European Union.

• Scotland – Through its joint venture in the SEGAL system in Northeast Scotland, ExxonMobil is progressing discussions to support the Acorn project, which will collect CO2 from the St. Fergus gas processing complex for transport and storage in offshore gas reservoirs.

• Singapore – ExxonMobil is planning a CCS hub concept to capture, transport and permanently store CO2 generated by industrial activity in the Asia-Pacific region. The project concept is based on a plan to capture CO2 emissions from Singapore manufacturing facilities for storage in the region.

• Qatar - ExxonMobil is a partner in several existing joint ventures with Qatar Petroleum that operate a CCS project with an annual capacity of 2.1 million tonnes at Ras Laffan. ExxonMobil is evaluating opportunities to add additional capture capacity in the region.

The new projects will complement ExxonMobil's current carbon capture capacity in the United States, Australia and Qatar, which totals about 9 million tonnes per year.

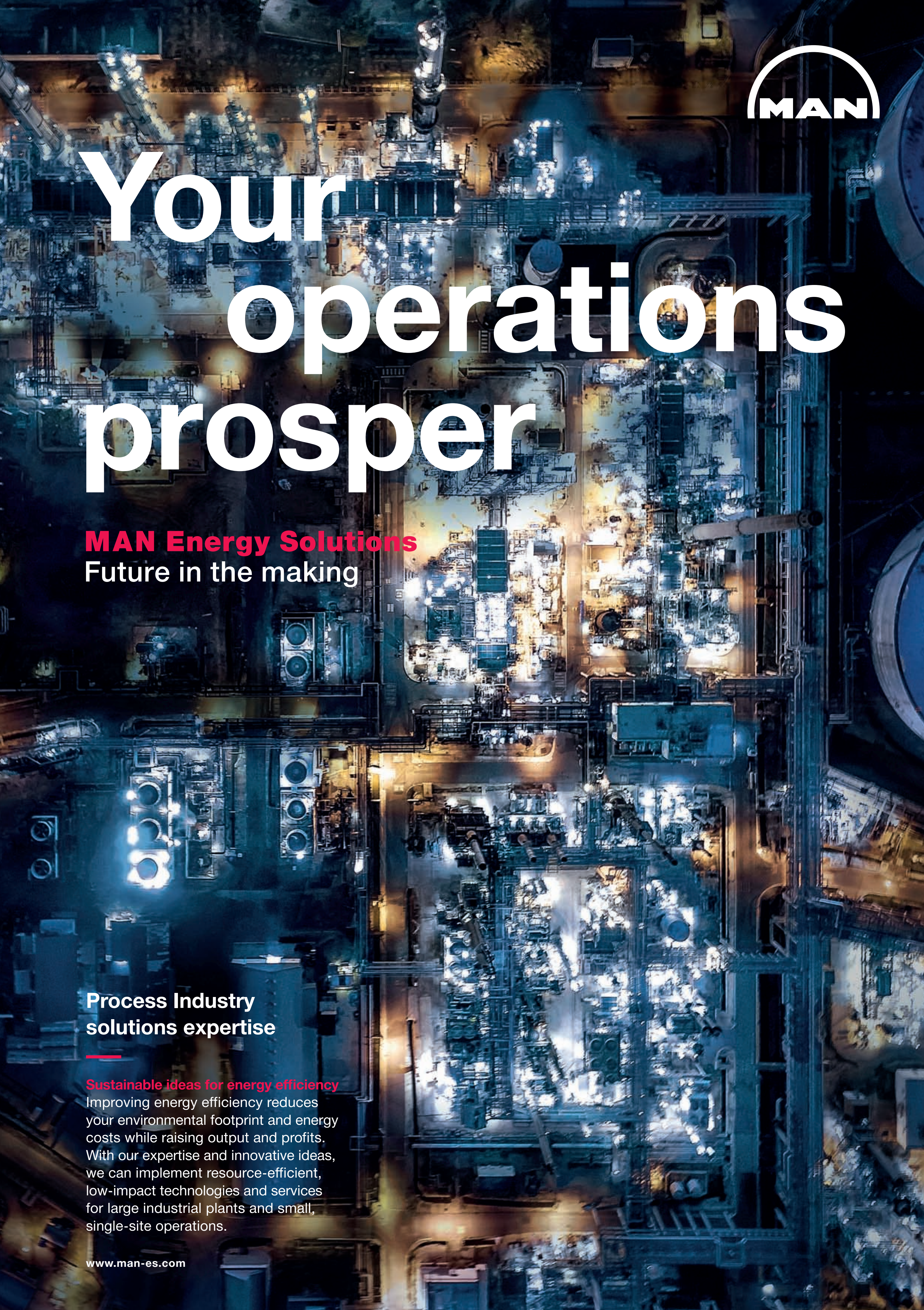
ExxonMobil is collaborating with multiple partners across industry, academia and government to advance carbon capture technologies to reduce costs and enhance scalability.

This includes the company's work with FuelCell Energy to advance carbonate fuel cell technology to more efficiently capture CO2 from industrial facilities, and Global Thermostat, a collaboration to advance efforts to capture CO2 directly from the air.

The company said CCS opportunities can become more commercially attractive through government policy, including the United States tax credit 45Q, which ExxonMobil supports, and other supportive policies in the European Union, Canada and Singapore.

More information

corporate.exxonmobil.com



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MIT- boosting the efficiency of carbon capture and conversion systems

Researchers at MIT have developed a method that could significantly boost the performance of systems that use catalytic surfaces to enhance the rates of carbon-sequestering electrochemical reactions.

Such catalytic systems are an attractive option for carbon capture because they can produce useful, valuable products, such as transportation fuels or chemical feedstocks. This output can help to subsidize the process, offsetting the costs of reducing greenhouse gas emissions.

In these systems, typically a stream of gas containing carbon dioxide passes through water to deliver carbon dioxide for the electrochemical reaction. The movement through water is sluggish, which slows the rate of conversion of the carbon dioxide. The new design ensures that the carbon dioxide stream stays concentrated in the water right next to the catalyst surface. This concentration, the researchers have shown, can nearly double the performance of the system.

The results are described today in the journal Cell Reports Physical Science in a paper by MIT postdoc Sami Khan PhD '19, who is now an assistant professor at Simon Fraser University, along with MIT professors of mechanical engineering Kripa Varanasi and Yang Shao-Horn, and recent graduate Jonathan Hwang PhD '19.

Dyes are used to reveal the concentration levels of carbon dioxide in the water. On the left side is a gas-attracting material, and the dye shows the carbon dioxide stays concentrated next to the catalyst.

Image: Varanasi Research Group at MIT

"Carbon dioxide sequestration is the challenge of our times," Varanasi says. There are a number of approaches, including geological sequestration, ocean storage, mineralization, and chemical conversion. When it comes to making useful, saleable products out of this greenhouse gas, electrochemical conversion is particularly promising, but it still needs improvements to become economically viable. "The goal of our work was to understand what's the big bottleneck in this process, and to improve or mitigate that bottleneck," he says.

The bottleneck turned out to involve the delivery of the carbon dioxide to the catalytic surface that promotes the desired chemical transformations, the researchers found. In these electrochemical systems, the stream of carbon dioxide-containing gases is mixed with water, either under pressure or by bubbling it through a container outfitted with electrodes of a catalyst material such as copper. A voltage is then applied to promote chemical reactions producing carbon compounds that can be transformed into fuels or other products.

There are two challenges in such systems: The reaction can proceed so fast that it uses up the supply of carbon dioxide reaching the catalyst more quickly than it can be replenished; and if that happens, a competing reaction — the splitting of water into hydrogen and oxygen — can take over and sap much of the energy being put into the reaction.

Previous efforts to optimize these reactions by texturing the catalyst surfaces to increase the surface area for reactions had failed to deliver on their expectations, because the carbon dioxide supply to the surface couldn't keep up with the increased reaction rate, thereby switching to hydrogen production over time.

The researchers addressed these problems through the use of a gas-attracting surface placed in close proximity to the catalyst material. This material is a specially textured "gas-philic," superhydrophobic material that repels water but allows a smooth layer of gas called a plastron to stay close along its surface. It keeps the incoming flow of carbon dioxide right up against the catalyst so that the desired carbon dioxide conversion reactions can be maximized.

By using dye-based pH indicators, the researchers were able to visualize carbon dioxide concentration gradients in the test cell and show that the enhanced concentration of carbon dioxide emanates from the plastron.

In a series of lab experiments using this setup, the rate of the carbon conversion reaction nearly doubled. It was also sustained over time, whereas in previous experiments the reaction quickly faded out. The system produced high rates of ethylene, propanol, and ethanol — a potential automotive fuel. Meanwhile, the competing hydrogen evolution was sharply curtailed. Although the new work makes it possible to fine-tune the system to produce the desired mix of product, in some applications, optimizing for hydrogen production as a fuel might be the desired result, which can also be done.

"The important metric is selectivity," Khan says, referring to the ability to generate valuable compounds that will be produced by a given mix of materials, textures, and voltages, and to adjust the configuration according to the desired output.

By concentrating the carbon dioxide next to the catalyst surface, the new system also produced two new potentially useful carbon compounds, acetone, and acetate, that had not previously been detected in any such electrochemical systems at appreciable rates.

In this initial laboratory work, a single strip of the hydrophobic, gas-attracting material was placed next to a single copper electrode, but in future work a practical device might be made using a dense set of interleaved pairs of plates, Varanasi suggests.

Compared to previous work on electrochemical carbon reduction with nanostructure catalysts, Varanasi says, "we significantly outperform them all, because even though it's the same catalyst, it's how we are delivering the carbon dioxide that changes the game."

"This is a completely innovative way of feeding carbon dioxide into an electrolyzer," says Ifan Stephens, a professor of materials engineering at Imperial College London, who was not connected to this research. "The authors translate fluid mechanics concepts used in the oil and gas industry to electrolytic fuel production. I think this kind of cross-fertilization from different fields is very exciting."

Stephens adds, "Carbon dioxide reduction has a great potential as a way of making platThere can be few who doubt that 2021, like 2020, will be remembered as a spectacularly difficult year, perhaps ranking alongside just a handful of other historical dates that have truly dreadful connotations. But, despite this cloud of gloom hanging over the months ahead, there is also the prospect that here in the UK it might also be remembered as the year CCS finally got off the ground and began to carve a path to a commercially viable future.

The research was supported by the Italian energy firm Eni S.p.A through the MIT Energy Initiative, and a NSERC PGS-D postgraduate scholarship from Canada.

More information

Varanasi Research Group:
varanasi.mit.edu

New process more efficiently recycles excess CO2 into fuel

A new study introduces an electrochemical reaction, enhanced by polymers, to improve CO2-to-ethylene conversion efficiency over previous attempts.

The results of the study led by University of Illinois Urbana-Champaign chemistry Professor Andrew Gewirth and graduate student Xinyi (Stephanie) Chen are published in the journal Natural Catalysis.

Allowing CO2 gas to flow through a reaction chamber fitted with copper electrodes and an electrolyte solution is the most common method researchers use to convert CO2 to useful carbon-containing chemicals, the study reports.

"Copper metal is highly selective toward the type of carbon that forms ethylene," Professor Gewirth said. "Different electrode materials will produce different chemicals like carbon monoxide instead of ethylene, or a mix of other carbon chemicals. What we have done in this study is to design a new kind of copper electrode that produces almost entirely ethylene."

Previous studies have used other metals and molecular coatings on the electrode to help direct the CO2-reduction reactions, the study reports. However, these coatings are not stable, often break down during the reaction process and fall away from the electrodes.

"What we did differently in this study was to combine the copper ions and polymers into a solution, then apply that solution to an electrode, entraining the polymer into the copper," Chen said.

In the lab, the team found that the new polymer-entrained electrodes were less likely to break down and produced more stable chemical intermediates, resulting in more efficient ethylene production.

"We were able to convert CO2 to ethylene at a rate of up to 87%, depending on the electrolyte used," Chen said. "That is up from previous reports of conversion rates of about 80% using other types of electrodes."

"With the development of economic sources of electricity, combined with the increased interest in CO2-reduction technology, we see great potential for commercialization of this process," Gewirth said.

The International Institute for Carbon Neutral Energy Research, Shell's New Energy Research and Technology and the National Science Foundation supported this research.

Gewirth also is affiliated with the Materials Research Laboratory at Illinois.

More information

chemistry.illinois.edu

2021 will be 'year to remember' for CCUS deployment in UK and Europe

Nick Cooper, CEO of Storegga Geotechnologies, the business behind the Acorn CCS project in Scotland explains why this year is going to be a turning point for CCS.

There can be few who doubt that 2021, like 2020, will be remembered as a spectacularly difficult year, perhaps ranking alongside just a handful of other historical dates that have truly dreadful connotations. But, despite this cloud of gloom hanging over the months ahead, there is also the prospect that here in the UK it might also be remembered as the year CCS finally got off the ground and began to carve a path to a commercially viable future.

It has been a long time coming. BP's DF1 project at Peterhead in Scotland was first talked about almost 20 years ago. Since then, there have been roughly as many CCS projects as there have been Governments – with none ever quite getting over the line. Most industry insiders agree though, this year, with a backdrop of legally binding net zero commitments by the middle of the century and the United Nations Climate Conference (COP26) arriving in Glasgow in November, feels very different.

At Storegga, we have welcomed the Government's efforts to provide the regulatory certainty that has historically been lacking for CCS. With clearer rules beginning to emerge around investment frameworks, signalling to industry a clear commitment to making CCS happen, and helping us, as independent CCS developers, to be able to articulate a much clearer and more appealing investment case to global infrastructure players and institutional investors.

The relatively recent change to the London Protocol which allows for the cross-border shipping of CO2 was another major step forward. And with more clarity promised by a Government that does genuinely seem determined to deliver on a green recovery, the Whitehall mood music is certainly upbeat.

Then there's the financial commitment. A billion pounds directed at getting two CCS projects up and running in the UK by the middle of the decade with a further two projects to follow by the end of the 2020s, is proof enough that there's more than just rhetoric designed to play to the growing green agenda. Much of the world is starting to see that clean CCS is taking off in North West Europe, and that presents truly global opportunities for companies at the forefront of this emerging sector.

It's not just the optics. There are some hard economic realities here too. The UK and Norway between us have ready access to about 90% of North West Europe's geologically appropriate storage resource – almost entirely in the North Sea. It makes sense then to capitalise on this to help drive forward our economies in the same way we did with North Sea oil and gas back in the mid-seventies.

That took a degree of national investment courage at the time. Fifty years on, the monetisation narrative is a little more complicated – how do you earn money from what is essentially a waste disposal business? But it's not so complicated – especially when big emitters who have no access to storage sites are beginning to consider what the costs might be of not capturing the CO2 they emit, not only financially but from a broader social licence to operate.

For those sectors that are harder to abate, such as aviation, and those whose emissions are in remote and logistically challenging locations we are developing solutions too. Establishing critical CO2 transportation and storage infrastructure in the UK through the likes of our Acorn Project in North East Scotland, enables a suite of other CO2 mitigation technologies to support the deep decarbonisation required to make net zero a reality.

One exciting option that we are actively exploring in the UK is Direct Air Capture (DAC). By capturing CO2 directly from the atmosphere, we get around the challenge of non-stationary and remote emitters - a US airline company could capture their CO2 emissions from a DAC plant in the UK, creating global customers as well as the opportunity for organisations to deal with their historic CO2 emissions.

Put this combination together and you really can see a corner being turned when it comes to being investable. Already there are a range of potential capital providers who are interested, as the rules of the game become clearer. They can start to see how they can not only do good with their own or the money they manage, but also make a return.

As clarity over the way CCS becomes commercially viable improves, we think we'll see the infrastructure players stepping in, perhaps some of the sovereign wealth funds, even pension funds. That's quite a considerable tap of capital to be turning on. Indeed, some of the big pension funds are already making their views known publicly when it comes to how their assets are invested.

It's going to be needed. Today, approximately 40 million tonnes of CO2 a year is stored globally. The UK alone currently emits approximately 360 million tonnes a year of CO2, so it's just a fraction of what's required. Some forecasters say we'll need five gigatonnes (that's a billion tonnes) of CO2 storage globally by 2050 – that means the world needs around 2,000 CCS projects by the middle of this century all operating efficiently and at scale. It's this calculation alone that's changing investors' minds.

At Storegga we are confident that with this new commercial focus on CCS development and scale up, 2021 could be the year to remember for CCS deployment in the UK and Europe.

More information

www.storegga.earth

theacornproject.uk

CCS to create blue hydrogen from natural gas – Zero Carbon Humber

The Humber region is the perfect location for the construction of a large-scale 'blue' hydrogen plant where the CO2 emissions from hydrogen production are captured and stored. By Stephen B. Harrison, sbh4 consulting

There are several heavily industrialised clusters in the UK. Merseyside in the north west is home to the Stanlow refinery and chemicals parks around Runcorn. Teesside in the north east was where the UK chemicals industry expanded in the 1950s and, until recently was a large steel-making location. However, regarding carbon dioxide (CO2) emissions, the Humber is the largest emitting cluster.

To the west of the Humber estuary is Drax power station, whilst on the north bank of the river is the Saltend Chemicals Park and on the south bank is Scunthorpe steel works and one third of the UK's refining capacity. According to the Government's Energy White Paper, The Humber industrial cluster yields 10 million tonnes of CO2 emissions per year, compared to Merseyside's 5 million and Teesside's 3.9 million.

Saltend Chemicals Park on the North bank of the Humber River. Equinor's H2H Saltend project will produce blue hydrogen by reforming natural gas whilst capturing its CO2 emissions, which will be stored under the North Sea

"If the UK is to decarbonise, then East Yorkshire must be a central part of the solution." That is how Dan Sadler, UK Low Carbon Strategy Director at Equinor emphasises the importance of working towards a carbon neutral Humber cluster.

"Blue hydrogen will be essential for deep and rapid decarbonisation. And there is no place better in the world for low carbon hydrogen production, storage, and utilisation than the Humber cluster in the UK. In this location, we have the perfect combination of natural gas supplies, renewable power generation and hydrogen demand."

Blue hydrogen from North Sea gas

An established natural gas pipeline infrastructure transports North Sea gas to the Humber industrial cluster. The main way to produce hydrogen at scale today is from natural gas using steam methane reformers (SMRs) or auto thermal reformers (ATRs). If the CO2 emissions from the SMR or ATR are captured, the resulting hydrogen is referred to as 'blue hydrogen', or 'Low Carbon Hydrogen' according to the EU CertifHy certification scheme.

Sadler adds that "the onshore and offshore geology around the Humber Estuary will enable super-scale underground hydrogen storage in salt caverns and offshore CCS to capture and store the CO2 emissions from hydrogen production from natural gas."

On the 27th of January, the European Parliament voted that blue hydrogen will be an acceptable bridge on the journey to full decarbonisation with green hydrogen. Whist that policy decision is not of direct impact to the UK, it demonstrates the growing international recognition that blue hydrogen is an essential component of our ambitions for rapid and deep decarbonisation.

Sadler explains his vision for the energy transition in the UK: "I believe that the production of blue hydrogen will create the business case to build storage and distribution infrastructure that can be used for green hydrogen in the future."

Achieving carbon neutrality through a transition from low carbon solutions to renewables

Equinor has committed to carbon-neutral operations by the year 2050 and is investing heavily in wind energy to meet that goal. Sadler develops the point further, adding: "until renewable power generation capacity ramps up sufficiently to make green hydrogen more cost-efficient, we will need low carbon bridging solutions based on fossil fuels combined with CCS. There are only 29 years until 2050. Alongside investment in renewables, blue hydrogen means we can act now to decarbonise quickly and at scale."

To enable industry around the Humber to use low carbon energy, the Zero Carbon Humber anchor project is the construction of the H2H Saltend large-scale blue hydrogen plant at the region's largest emitting chemicals park. "We are planning for at least 95% CO2 capture and sequestration from the hydrogen production facility", confirms Sadler. "That means that there will be some CO2 emissions, but they can be offset against bio-energy CCS (BECCS) elsewhere in the scheme."

Looking at the bigger picture around the Humber Estuary, the net-zero carbon emissions target can be achieved because the Drax power plant runs predominantly on biomass and future implementation of BECCS from its emissions would make it a carbon-negative power generation facility.

In a net-zero future, CO2 from the industrial cluster will be transferred out to the North Sea in a pipeline to safely store the gas in suitable underground geological formations. Sadler adds that "Equinor has more than 20 years of experience operating CCS schemes in the North Sea." The first of these involves the Sleipner West gas field in the Norwegian sector.

"The second Equinor CCS scheme started up in 2007, with its first CO2 injections in 2008. It is linked to the Melkøya LNG plant at Hammerfest, 500 Km inside the arctic circle", says Sadler. Equinor is also leading the Northern Lights project which will transport and store CO2 from various locations. In that scheme, liquefied CO2 is shipped from a cement factory to an onshore terminal in western Norway before it is compressed to high pressures and injected deep underground for permanent offshore storage.

CCS and underground hydrogen storage – geology is the key

One of the applications of hydrogen produced in the emerging Humber cluster will be domestic heating. That is a challenging application in terms of balancing supply and demand, as domestic heating is extremely seasonal.

"I come from Yorkshire, so I know what the weather is like around the Humber", says Sadler. "We use lots of gas in the winter but in the summer, there is less demand. This seasonal fluctuation can be balanced with large-scale storage which can reduce the cost of the overall scheme. We must develop infrastructure that provides affordable energy to the public and maintains the competitiveness of UK industry."

One of the reasons that the Humber is ideal for an integrated low-carbon hydrogen production, storage and utilisation cluster is the presence of underground salt strata. It is possible to create very large caverns in the salt that can be used as gas-tight hydrogen storage chambers. Unlike CCS, where the CO2 is permanently buried under ground, these caverns in the salt are like hydrogen storage tanks that can be filled and emptied as required.

Underground hydrogen storage is used in Texas as a strategic reserve of hydrogen to support refineries and petrochemicals customers. Salt caverns at Teesside have been in use for hydrogen storage since 1972. Worldwide, there are many underground salt caverns used to store natural gas and other hydrocarbons.

"We cannot choose where the salt is, just as we cannot influence where the optimum geology exists for CCS", says Sadler. "But our geological surveys show the conditions in East Yorkshire are ideal for salt caverns, so we can work in harmony with the natural features around the Humber Estuary and use these underground salt formations to enable decarbonisation."

More information

www.zerocarbonhumber.co.uk

sbh4.de

Carbon Capture for marine and offshore industries

Carbon Capture is a potential supplemental solution for reducing a vessel or offshore unit's overall carbon footprint says the American Bureau of Shipping (ABS) in an article as part of its Offshore Thought Leadership Series.

Unless a vessel or offshore unit is combusting zero carbon content fuels such as ammonia and hydrogen, other carbon-based fuels such as liquefied natural gas, liquefied petroleum gas, methanol, bio or renewable diesel and dimethyl ether will produce CO2 as a byproduct after combustion.

If the carbon-based fuel is produced renewably, the overall carbon footprint might be reduced, or even become net zero. CCS for shipboard application refers to a set of technologies that can be used to capture CO2 from vessel or offshore unit exhaust gas and store it for subsequent disposal or use.

Over the last 20 years many research groups around the world have explored carbon capture technologies to increase efficiency and reduce the size and cost of the system.

CO2 has been safely transported and used in many industries for decades and can be moved by ship, truck or pipeline.

The majority of carbon capture systems have been designed and demonstrated in electric power plants. However, it is possible to deploy CCS technologies onboard vessels or offshore units to capture, store and transfer CO2 ashore for use. Maritime deployment of CCS is now being researched and piloted by multiple firms.

Capture methods

There are three major types of CO_2 capture systems: post-combustion, pre-combustion, and oxyfuel combustion. Pre-combustion and oxy-fuel combustion remove carbon from the fuel prior to combustion and produce hydrogen and oxygen, respectively, for combustion. Consequently, the pre-combustion and oxy-fuel combustion carbon capture systems require integration into the fuel supply and power generation systems and calls for a total redesign.

Post-combustion process captures CO_2 from flue gas produced after the combustion and therefore can be added to the conventional design with minimal alteration to the engine. Retrofit to vessels or offshore units as a standalone system is relatively straightforward.

In the most-conventional capture based on solutions of liquid amines, there are two steps to separate CO_2 from the emission: capture (sorption) followed by thermal or pressure-swing desorption, also termed regeneration.

In capture, the CO_2 is absorbed into a liquid or solid by contacting the CO_2 source with the absorber. In the desorption/regeneration step, CO_2 is selectively desorbed from the absorber, resulting in a flow of pure CO_2 gas, with the original amine sorbent regenerated for further use.

Regulatory Requirements and Current Standards

In general, regulations and policies for carbon capture are mostly in development, with Europe being a notable early adopter. The European Union's carbon capture directive on Geological Storage of Carbon dioxide came into force in 2009, providing regulatory requirements for storage.

The United Kingdom's (U.K.) Department of Energy and Climate Change also has projects in motion to support the relatively new technologies. In the United States the Environmental Protective Agency is working on developing regulations to track national carbon capture activity and ensure safe practices.

The 2005 IPCC Special Report on Carbon Dioxide Capture and Storage covers maritime considerations for carbon capture and storage in Chapter 4 including considerations for design, construction, operation, risk, safety, and costs.

Onboard Considerations

The challenge in marine and offshore environment is the handling and storage of captured CO_2. The process requires significant power to liquefy or solidify the captured CO_2 for storage. Storing CO_2 in gaseous form onboard is not a viable option due to space requirements.

CO_2 transforms from gas to solid directly when cooled at ambient pressure and solidifies at -78 °C. It can also be solidified by interaction with other chemicals.

To transport CO_2 in a liquid state it needs to be contained at 0.7 MPa and -50 °C. If the liquefied CO_2 is to be stored onboard, the storage space should be considered based on the expected capture during voyage; 1 ton of liquified CO_2 occupies about 1 m^3 volume.

Current Research

Offshore CCS projects offer CO_2 storage opportunities through use of existing or plugged/abandoned wells. Research projects in partnership with the Bureau of Ocean Energy Management are collecting data on key offshore storage complexes along the US Mid-Atlantic, Southeast and Gulf of Mexico.

These projects and assessment efforts use 3D flow and geo-mechanical modeling and investigate sites with potential to store millions of metric tons of CO_2.

Mitsubishi Heavy Industries (MHI) recently conducted a concept study focused on installing a carbon capture and storage unit on a very large crude carrier. The system was comprised of four towers for cooling the exhaust, absorbing CO_2, treating the exhaust, and regenerating the CO_2, in addition to the required liquefaction and storage facilities.

The objective of the project was to investigate onboard production of methane or methanol by combining hydrogen from water electrolysis with the captured CO_2. MHI reported the CO_2 capture rate at about 86%, and a 20-year rate of return due to the high CAPEX and OPEX.

The U.K.'s Department for Transport recently funded a project by PMW Technology with an A3C carbon capture process, partnered with a naval architect company, Houlder Ltd. to study the potential for using carbon capture technology in shipping. They will use their A3C carbon capture process to extract CO_2 from exhaust gases by freezing, then subliming the CO_2. The CO_2 will then be liquified and stored in tanks onboard the ship.

Presently, carbon capture technology is facing technical and economic challenges for marine and offshore applications. However, it still has potential to be an effective method of reducing GHG emissions for future vessels and offshore units, especially in conjunction with low-carbon fuels. Further technical advances are expected to reduce the scale, cost and complexity of the carbon capture technology.

Role of ABS

Decarbonization is a major component of sustainability. However, sustainability also means sustaining businesses in challenging times beyond environmental aspects including items such as alternative energy sources for lower carbon footprint, new approaches to vessel/asset design to enhance performance, digital solutions to optimize asset management and additional strategies that impact safety, security and the environment.

Through the Offshore Sustainability Online Resource Center, ABS addresses topics of operational sustainability, environmental sustainability, and digital sustainability.

These services are in addition to typical Classification services such as operational safety of production units and unmanned offshore installations, offshore compliance and regulatory issues, and industry research that examine emerging sustainability issues in the offshore industry.

ABS is also working with the Massachusetts Institute of Technology on maritime carbon capture strategies for emissions reduction and CO_2 mitigation technologies.

The studies are taking into consideration the relative sizing for potential onboard systems as well as the modeling of system performance for exhaust flow, efficiency, and CO_2 reduction potential of multiple vessel sizes and profiles.

More information

For more information, visit the ABS Sustainability portal at:
ww2.eagle.org/en/Products-and-Services/Sustainability.html

Equinor's progress with Longship and Baker Hughes' CO2 capture business

Equinor has already signed MOUs with 9 companies around Europe for its Longship CO2 storage project, says Hege Rognø, head of research and technology with Low Carbon O&G technologies, Equinor at the Baker Hughes annual meeting (online) on Feb 1.

As of Feb 1 2021, Equinor has already signed Memoranda of Understanding with nine companies around Europe for its Longship / Northern Lights CO2 capture and storage project, said Hege Rognø, Head of research and technology with Low Carbon O&G technologies, Equinor.

These are Heidelberg Group in Germany (cement), Fortum Group in Finland (waste to energy), Ervia in Ireland (natural gas supply), Air Liquide in Belgium (chemicals / hydrogen), Stockholm Exergi in Sweden (waste to energy), ArcelorMittal in Luxembourg (iron / steel), Preem in Sweden (refineries, fuels, hydrogen). All these companies are considering providing CO2 to store in Longship.

The sectors thought to have highest potential as clients are waste incineration and cement. "We're building the market at the same time as building the project," she said.

Longship also has MOUs with Swiss research university ETH Zurich and Microsoft.

The initial customer will be the Klemetsrud waste-to-energy plant in Oslo. It will capture CO2 from its flue gas, compress it and put it in a ship for transport to Northern Lights' terminal near Bergen. Two ships will be used initially, with a standard LPG design, with LNG fuel. The vessels will have 7,500 m3 capacity. The CO2 emissions from the ships during transit works out about 1.5 per cent of the CO2 being carried.

Any company can be a customer of the "Northern Lights" CO2 storage, if they can deliver CO2 to its facility near Bergen by ship.

But as the project scales up, more ships will be required. Perhaps the shipping component will be a test bed for zero carbon maritime fuel technology (building on Equinor's planned hydrogen production), she said.

Construction has already started on the vessel receiving terminal near Bergen. The terminal is planned to be remotely controlled.

At the terminal, CO2 will be put in temporary storage, then sent in a 100km pipeline for subsurface storage in a saline aquifer, 2500m deep. The aquifer has sealing caprock above it. Equinor has modelled how it expects the CO2 to flow in the subsurface,.

A structure was installed above the injection well site in 2019, and a well drilled in 2020.

One of the most important issues is building up confidence that CO2 capture and storage is safe, Ms Rognø said.

To build confidence, it emphasises that it has been injecting CO2 in its Sleipner field since 1996, and in its Snøvhit field since 2008. All data for Sleipner is made public.

It also emphasises the extensive testing on CO2 capture technology which has been done at its "Technology Centre Mongstad" research centre. There have been test "campaigns" both with proprietary technologies owned by various vendors, and scientific non-proprietary tests. Understanding has been developed about solvents, energy efficiency and emissions. The centre is planned to continue operations until 2023.

Other projects

Equinor is involved in a range of other CCS and hydrogen projects.

It is involved in the UK's "Northern Endurance" partnership to store CO2 from the Teesside and Humber carbon capture projects, storing CO2 in saline aquifers and depleted oil fields in the North Sea.

On the hydrogen side, it sees "blue" hydrogen, made from gas with CCS, as the main way to supply large volumes of clean hydrogen at relatively low cost, and speed up development of the clean hydrogen market.

In Norway it plans to produce hydrogen for ship fuel. In the Humber industrial area (UK) it plans to develop a "blue" hydrogen production plant to supply industry and power markets. The hydrogen may be further processed to make blue ammonia, which could be more useful as a marine fuel, being easier to handle.

There is a project in the Netherlands to convert Vattenfall's "Magnum" gas field plant to run on hydrogen. It has a project "NortH2" to provide green hydrogen from an offshore wind farm in the Netherlands.

It is exploring using a CO2 capture unit onboard an FPSO, to handle emissions from offshore fields. For example, if there is a gas production line which is rich in CO2. Rather than take the CO2 onshore for separation (as happens in Sleipner and Snøvhit), the CO2 can be removed directly on the FPSO and then sequestered.

This may be a suitable application for the Compact Carbon Capture (3C) technology, which Equinor had a part in developing, and has now been acquired by Baker Hughes. 3C's technology is designed to take up much less space than conventional carbon capture plant, and so may be more suitable for use offshore. The technology would need to be "qualified" for offshore use, but "I believe that to be not too far away," she said.

After capturing the CO2, it can be compressed onboard the FPSO, and then mixed with water being injected into the aquifer for purposes of maintaining pressure in the reservoir. Or it could be sequestered in a separate reservoir.

As a general point, one way to reduce the costs of CO2 sequestration could be to reduce the cost of drilling CO2 wells, she said. "The well cost has to come down dramatically compared to what we have in the oil and gas industry."

Baker Hughes' CO2 capture approach

In November 2020, Baker Hughes announced that it was acquiring Compact Carbon Capture, a Norwegian technology development company which goes under the short name "3C".

3C uses rotating beds instead of the usual static, gravity based columns to bring the flue gases in contact with solvent. In the rotating beds, the heavier liquid is thrown outwards with centrifugal force, rather than being poured down through a column with gravity.

The rotating bed system takes up much less overall volume, and about 75 per cent smaller footprint (ground space), than the gravity column system. This means a big reduction in capital cost, and makes it easier to install on existing ("brownfield") installations where there is less free space.

The 3C plant also combines the reboiler (where the solvent is heated) and the desorber (where the attached CO2 is disassociated and removed), so there is one less piece of equipment involved. These are small enough to fit into a standard ISO box container.

The whole system can operate at higher pressure – 20 bar – which can improve the transfer processes, and also means that CO2 can be released at 20 bar, so it needs less additional compression before putting into a pipeline or ship.

The technology was developed by a collaboration between Fjell Technology Group, Equinor, Prototech and SINTEF, with first patent granted in 1999, and 3C established as its own company in 2018.

As of February 2021, Baker Hughes / 3C is testing a 5 tonne per day unit at an Equinor facility, and plans to increase to 30 tonnes per day in 2021, then move to industrial sized units.

Baker Hughes plans to make the 3C unit in a standard module size, in mass production, says Torleif Madsen, Compact Carbon Capture Product Manager, Baker Hughes C3 Venture.

For example, the standard size module could be for a 10,000 tonne per annum (30 tonnes per day approx.) capture rate, or a 250,000 tonne per annum capture rate. For larger capture rates than this, customers would use multiple modules.

One of the reasons Baker Hughes acquired 3C is that it can provide a pathway to "one of the cheapest, if not the cheapest form of carbon capture that's currently out there," whilst also providing a high capture performance, says Rod Christie, EVP turbomachinery and process solutions with Baker Hughes.

The 75 percent smaller footprint gives it "a big advantage when you bring [CCS] into existing facilities, where real estate isn't readily available," he said.

The system is also being designed to operate with as little maintenance and as most automation as possible, which will also help reduce costs, particularly when it is used offshore. Offshore, a carbon capture unit like 3C could be used to separate CO2 from a CO2 rich gas production stream.

Another application is using it on the flue gas of a gas turbine, burning gas which has just been produced. Zero carbon electricity can then be brought on shore.

Or perhaps in future, it could be linked to a steam methane reforming (SMR) plant which produces hydrogen from methane, with the hydrogen brought onshore. Doing SMR offshore "is not impossible to do, it is just marinization of a process," Mr Christie says.

Ammonia solvent

For the solvent in the 3C unit, Baker Hughes is exploring using chilled ammonia.

The required "chilling" depends on the temperature, because the solvent will need to be in liquid form. At atmospheric pressure, ammonia boils at -33.34 °C. If the whole system is pressurised to 20 bar, it boils at 50 °C.

Ammonia is a commodity chemical, so the customer is not tied to any solvent supplier, says Gianluca Di Federico, head of carbon capture business development with Baker Hughes. It is possible to manufacture ammonia with a low carbon footprint, such as making it from blue hydrogen.

The chilled ammonia process can be used for any type of flue gas, he said.

Ammonia is tolerant to oxygen and flue gas impurities, such as oxides of sulphur and nitrogen, he says. It does not degrade over time, as some other solvents do. The chemistry is comparatively simple. In testing, 90 per cent separation was demonstrated.

The flue gas from gas turbines contains a large amount of oxygen (from the air which the gas was combusted in), and this can cause degradation of normal solvents like amines, he said. These solvents will also degrade in general over time. There is a cost of disposing the degrading solvent and adding fresh solvent.

Baker Hughes' CCS offering

As well as owning 3C, Baker Hughes has a number of business offerings relating to CCUS, including consulting and feasibility analysis, making "turbomachinery" equipment for CO2 compression, including equipment which can be used offshore. It can manage subsurface storage, including leak and caprock integrity monitoring.

The company is investing into its carbon capture offerings, as it observes a change happening in the attitude of investors and the public, with more and more people believing it is time to do something about CO2 emissions "in a more joined up and serious way," said Rod Christie, EVP turbomachinery and process solutions with Baker Hughes. "We're in that tipping point."

Baker Hughes is already active in about 20 CCS projects in various forms, between concept design, pre-FEED, FEED, up to the FID stage, he says.

When carbon capture costs can get below about $120 a tonne, "you trigger the ability to move projects forward," Mr Christie believes, based on internal CO2 costs set at some companies, or carbon prices set by some governments.

Mr Christie estimates that Eur 120 ($145) / tonne is currently towards the lower end of capture costs from equipment currently available. "We would look to halve that to Eur 60."

Baker Hughes is comfortable with the challenges of ensuring that carbon capture equipment can operate reliably offshore, even when there is a risk of CO2 and water mixing to create corrosive carbonic acid.

More information

The full meeting is available at:
am2021.bakerhughes.com

Advances in Direct Air Capture of CO2

Although it will always be easier and cheaper to capture CO2 at source, Direct Air Capture (DAC) offers a method to abate historical emissions already in the atmosphere says a report from The Catalyst Group Resources. If combined with low carbon energy and CO2 storage it is a viable negative emissions technology, but rapid scale up is required to meet climate goals and costs remain high.

Direct Air Capture is one of a number of methods to reduce CO2 in the atmosphere to meet climate goals, however due to the requirement to capture CO2 at atmospheric concentrations DAC requires three times more energy to capture the same amount of CO2 compared to the exhaust of a coal-fired power plant and is therefore one of the more expensive Negative Emissions Technologies (NETs). Climeworks estimates it can bring the cost down to $100/ton by 2030.

It is important to note that most DAC companies currently utilize captured CO2 commercially for their demonstrations, making their impact carbon neutral at best. If the energy resource is fossil fuel based then the net carbon removed is also subsequently reduced. In order to be carbon negative, DAC must be combined with carbon storage and use low or zero CO2 energy pathways and this limits where they may be sited.

Outline of the Direct Air Capture process

• In the DAC process , ambient air is captured, and the CO2 is separated from air through a chemical separation process. Thereafter heat, vacuum, or some combination is applied to the system, producing high purity CO2 , which can be easily condensed through compression, then transported and stored geologically or used commercially.

• Today's DAC technologies that convert low purity CO2 (i.e., atmospheric) to high purity (e.g., 98%+), are very energy intensive, with thermal energy dominating over electric. While costs will come down, thermodynamics sets a lower limit.

• Roughly 80% of the total energy required is thermal, which is used to regenerate the capture material, while the remaining 20% comprising the electrical energy is used to run fans, pumps, compressors, etc.

• The thermal energy for today's commercial technology is roughly 6 GJ/t CO2 , while the electrical energy is approximately 1.5 GJ/t CO2

• Finding the best opportunities for DAC to begin commercializing today does not necessarily align with the ultimate markets for DAC as a negative emissions technology.

Technically, there is no limit on the potential impact that DAC may have. In other words, it does not require arable land, nor do all of the technologies require significant amounts of water. An additional benefit is that DAC may be co-located with geologic storage sites or with low-carbon energy resources.

On the other hand, a major drawback of DAC is the energy requirement. Today, with Climeworks realizing costs at $600/tCO2 removed from the air, DAC may be too expensive to be

deployed on a significant enough scale to positively impact climate. The capital investment is also sizeable. Since contactors must have a high cross-sectional area to capture enough air to collect high amounts of CO2 this drives up the cost as demonstrated in Figure ES-1.

One of the ways that the high costs of DAC may be offset is through the beneficial re-use of CO2. There are several applicable markets such as food and beverages, materials, synthetic fuels, enhanced oil recovery (CO2-EOR) as well as public financing through the purchase of carbon-offset credits. These markets may assist in subsidizing the costly plants today thereby accelerating their potential deployment and scale-up.

It is important to note that utilization of CO2 is at best net neutral in terms of emissions. DAC is only a true negative emissions technology (NET) if it is paired with permanent storage underground or in a mineral/product on the order of 1000 years (NASEM, 2019).

In general, all DAC processes that may be used to remove CO2 from air roughly follow the same steps. First, the air is blown through an air contactor using fans to overcome pressure drop. Here, the CO2 in the air binds to the chemical sorbent. Next, the sorbent is heated and, in some processes, also exposed to a vacuum. This causes the CO2 to be released subsequently regenerating the sorbent so it can bind more CO2 upon subsequent cycles.

DAC technologies may be divided into two main categories by the kind of chemical filter they use, i.e., solid versus solvent sorbents. Solid sorbents used are small micro and mesoporous particles which allow for a high surface area to adsorb or complex the CO2. These are embedded within a honeycomb structure with parallel channels having diameters on the order of millimeters to minimize pressure drop. Alternatively, solvents are pumped downwards through the contactor cross-current to the fan-blown air. The column is filled with packing materials to increase the gas-liquid contact.

To meet climate goals DAC will need to be scaled up to gigaton (Gt) levels of CO2 removal per year by 2050. With current pilot and demonstration plants only capable of kiloton (kt) annual CO2 removal, the industry will require a rapid level of growth unattained so far by most technologies.

Fortunately, the photovoltaics (PV) industry may be an indicator as to how DAC might be able to achieve this. While advancements in manufacturing and conversion efficiency enhanced PV's growth, a study by Kavlak et al. (2018) demonstrated that various government policies accounted for approximately 60% of market growth of PV.

DAC could find market success with prices of \$100/ton CO2, but today's \$600/ton cost makes it prohibitive for early customers to provide investments needed to begin to drive prices down. This makes it clear why policy is so important if DAC is be scaled up in a timely manner.

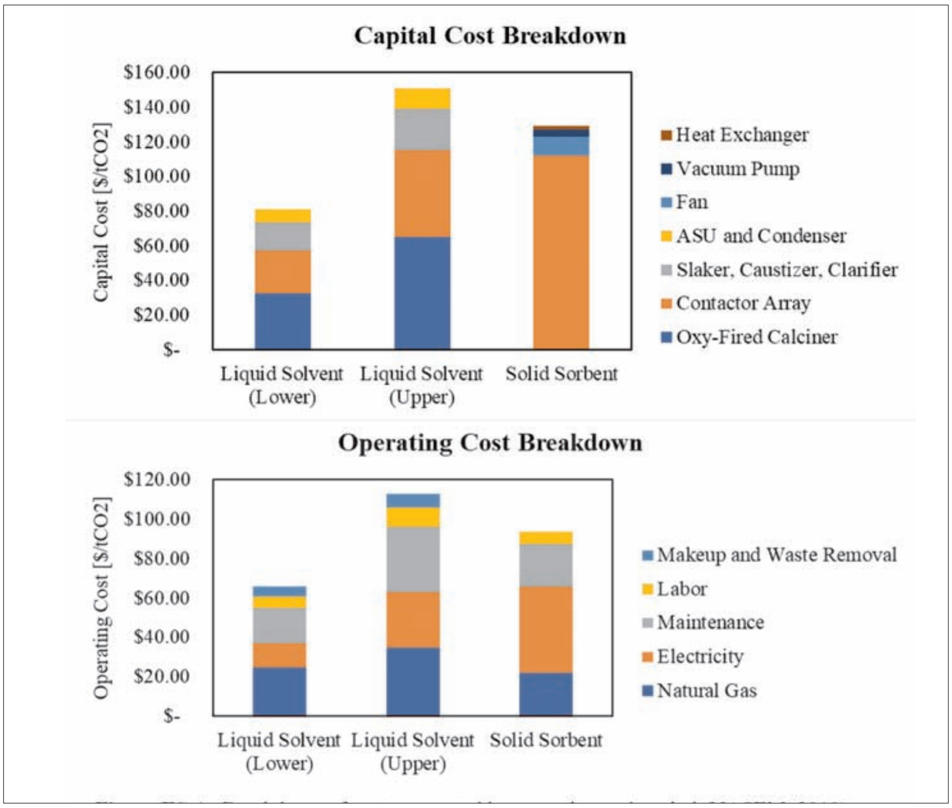
Some policies are already in place, such as the federal tax code 45Q and California's Low Carbon Fuel Standard Program, which will help to bridge the gap, but further subsidies may be required to further accelerate growth.

Current commercial activity

CLIMEWORKS is a Swiss company whose technology utilizes a solid sorbent system to capture ambient CO2. They currently offer a range of products including a demonstration plant capable of capturing 2 tons of CO2 per year, and large scale plants that can capture from 50 to 1,800 tons of CO2 per year.

GLOBAL THERMOSTAT is based in New York and features a dry amine based solid sorbent DAC process. Its strategy is to capture CO2 and sell it for a range of utilization applications including food and beverages, plastics, building materials, greenhouses, biofertilizers, industrial gases, EOR and fuels.

CARBON ENGINEERING is a Canadian company with a pilot plant for removing CO2 from the air which employs a liquid solvent based capture process. Its key focus is turning CO2 into fuels using its DAC and AIR TO FUELS™ processes.



Breakdown of costs separated by operating and capital (NASEM, 2019)

SILICON KINGDOM HOLDINGS is a Dublin based company currently developing the moisture swing adsorption (MSA) technology created by researchers at Arizona State University. The company uses the principle of MSA combined with a CO2 purification process to capture CO2 for sequestration or beneficial reuse.

ANTECY is a Netherlands company that uses adsorption based DAC coupled with electrolysis for hydrogen (H2) production to create methanol. This methanol effectively stores this excess energy.

HYDROCELL is a Finnish company uses novel sorbent technology paired with cyclic temperature vacuum swing adsorption (TVSA) to capture CO2 directly from the atmosphere.

Company	System Type	Technology	Regeneration	Purity/ Application	Scale
Carbon Engineering	liquid solvent	Potassium hydroxide solution/ calcium carbonation	temperature	99%	pilot 1 t/d
Climeworks	solid sorbent	amine-functionalized filter	temperature or vacuum	99% w/dilution depending on application	demonstration 900 t/y
Global Thermostat	solid sorbent	amine-modified monolith	temperature and/or vacuum	99%	1000 t/y
Infinitree	solid sorbent	ion-exchange sorbent	humidity	3-5% algae	Laboratory
Skytree	solid sorbent	Porous plastic beads functionalized with benzylamines (Alesi and Kitchin, 2012)	temperature	air purification, greenhouses	Appliance
Silicon Kingdom Holdings	solid sorbent	Anionic exchange membrane	humidity	3-5%	pilot 1 t/d
Hydrocell	solid sorbent	Amine-functionalized polystyrene beads	Temperature and vacuum swing	Excess solar energy storage	pilot 1.387 t/y

Selected companies working to commercialize DAC systems (TCGR 2019)

Technology summary

The types of systems outlined in the report include:

- adsorption (solid sorbents)
- absorption (liquid solvents)
- moisture swing adsorption (ionic exchange resins)
- electrochemical DAC (solutions with complexing agents)

Each of the different types of DAC technologies have distinctive advantages, disadvantages and areas for improvement. Each DAC technology is broken down by the major differences between that technology and other DAC technologies.

This is expanded to include how these differences potentially affect the capital and operating costs of an industrial scale DAC system.

Electrochemical DAC has not been as rigorously studied as the above named processes. On account of this, there may be considerations for this technology that will become more apparent as increased testing takes place on a bigger scale.

Outlook

The markets for CO2 are relatively small compared to global CO2 emissions. Some of these markets include EOR, food and beverage, building materials, plastics and chemicals.

Although the fuel market has the potential to be significant, it should be noted that the approach involving CO2 plus H2 to synthetic fuels is at best neutral and is not a NET. Hence, this pathway will assist in avoiding emissions through the direct use of fossil fuels but will not be a route to permanently remove the already emitted CO2 from the atmosphere.

Although many of the utilization markets are at best carbon neutral, they may play a critical role in enabling DAC to scale up from the kiloton to megaton scale.

Regardless of how much technology is advanced to bring the costs of DAC down, there will be a need for policies surrounding carbon to assist in subsidizing DAC as NET in order to ultimately impact climate.

High capital dominates the cost of DAC today rather than the thermal energy. Other research areas may also focus on reducing operating costs of DAC. The development of low cost sorbents and the scale up of durable sorbents may be a useful area of future research.

Given that the thermal requirement of DAC is a significant component, researching advanced solvents with lower thermal regeneration requirements may be beneficial.

Life cycle analyses coupled to techno economic analyses of DAC systems are vital to help identify further areas that require additional RD&D.

References

Kavlak G, McNerney J, Trancik JE (2018) Evaluating the causes of cost reduction in photovoltaic modules. Energy Policy 123(August):700–710.

NASEM. 2019. Negative Emissions Technologies and Reliable Sequestration. Washington, D.C.: National Academies Press. https://doi.org/10.17226/25259.

Previous articles

This is the third in a series of articles summarising key reports from The Catalyst Group Resources Carbon Dioxide Capture and Conversion (CO2CC) Program. Don't miss "Technical and Commercial Progress Towards Viable CO2 Storage" and "Compact Light-Weight CO2 Capture Technologies for Small- to Medium-Scale CO2 Emitters" which featured in the previous issues.

More information

For information about this and other services of the CO2CC Program:

www.catalystgrp.com/tcg-resources/member-programs/co2-capture-conversion-co2cc-program

Drax applies to build BECCS power plant

Drax is to kickstart the planning process for its proposals to build commercial negative emissions technology, bioenergy with carbon capture and storage (BECCS) in the UK.

Work to build BECCS could get underway at Drax as soon as 2024, creating tens of thousands of jobs and supporting a post-covid economic recover the company said.

By 2027 Drax's first BECCS unit could be operational, delivering the UK's largest carbon capture project and permanently removing millions of tonnes of carbon dioxide from the atmosphere each year.

In order to deploy the technology Drax must secure a Development Consent Order (DCO) from the government – a process which takes around two years to complete, and which will get underway in March.

Will Gardiner, Drax Group CEO said, "Kickstarting the DCO process this March is a landmark moment in deploying BECCS at Drax and delivering against our ambition to be a carbon negative company by 2030.

"At Drax we are very proud of the great strides already made in transforming the business to become the UK's largest single site renewable power generator, producing enough renewable electricity for up to four million homes and protecting thousands of jobs in the process.

"With BECCS we can go even further – we will be permanently removing millions of tonnes of CO2 from the atmosphere and making a significant contribution to efforts to address the climate emergency, whilst creating thousands of new jobs and supporting a post-covid, economic recovery."

Drax recently announced the proposed acquisition of Pinnacle Renewable Energy Inc – a Canadian wood pellet producer. The deal, which is subject to shareholder and other approvals, would double Drax's own biomass production capacity, in line with its strategy to increase self-supply, reduce costs and create a long term future for biomass – paving the way for the deployment of BECCS.

If successful in its DCO application, and subject to the right investment framework from government, work to build Drax's first two BECCS units could get underway in 2024, ready to start capturing and storing up to eight million tonnes of CO2 a year.

The first phase of the DCO application process includes an informal public consultation during March, when people can provide comments on Drax's proposals for BECCS via the project website.

More information

beccs-drax.com

Projects and policy news

Summit Carbon Solutions develops 'world's largest' CCS project

www.summitag.com

Summit Carbon Solutions will lower the carbon footprint of biorefineries and other carbon dioxide emission sources throughout the Midwestern region of the United States.

Summit Agricultural Group has created Summit Carbon Solutions, a new business platform that will address the global challenge of decarbonization by developing the world's largest carbon capture and storage project.

When fully developed, Summit Carbon Solutions will have an infrastructure network capable of capturing and permanently storing more than 10 million tons of carbon dioxide annually.

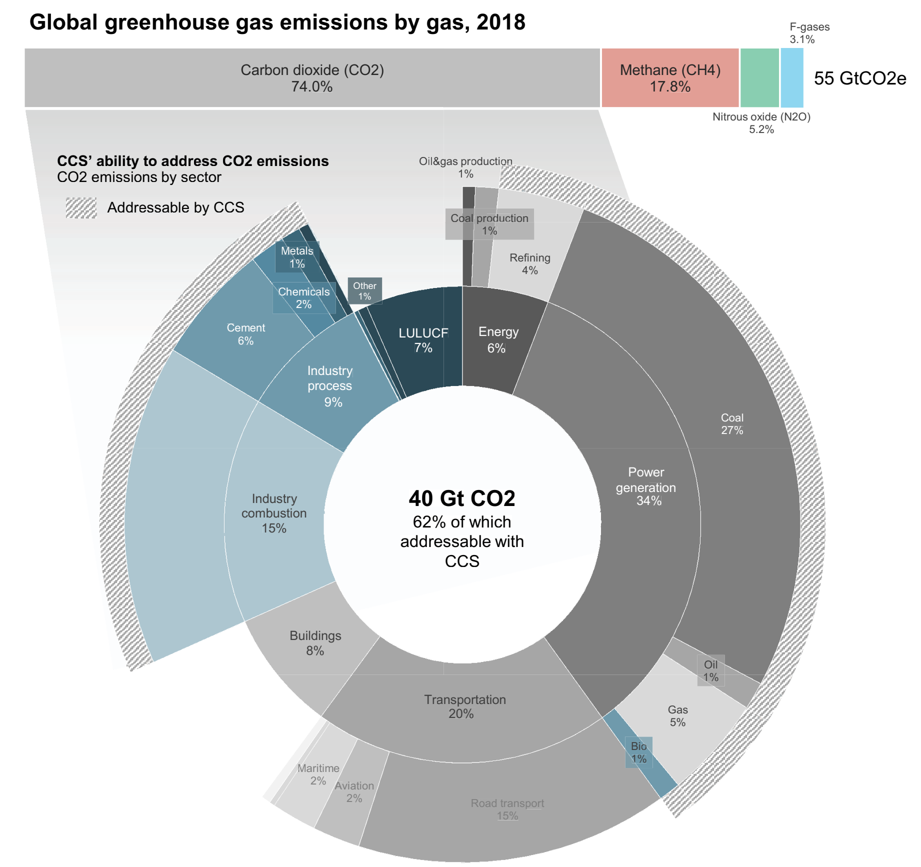
Summit Carbon Solutions has partnered with a group of leading biorefiners located in Iowa, Minnesota, South Dakota, and North Dakota to execute the first phase of the project, which will put them on the path of ultimately delivering a net-zero-carbon fuel.

In addition to biorefiners, Summit Carbon Solutions will partner with other industries throughout the Midwest that have carbon reduction goals to help them capture and store their carbon emissions.

"This is a giant leap forward for the biofuels industry," said Bruce Rastetter, CEO of Summit Agricultural Group. "Carbon capture and storage is a future-focused solution that allows the biorefiners to lower their already attractive carbon footprint by up to 50 percent."

"Simply put, this will be the most impactful development for the biofuels industry and Midwestern agriculture in decades," Rastetter added. "We are grateful for our partnership with a significant group of forward-thinking biorefiners who have agreed to partner with us on this exciting new venture."

Summit Carbon Solutions is proceeding with initial engineering, design and permitting associated with the project, which will permanently store carbon dioxide in underground saline geologic formations.



Source: Rystad Energy research and analysis, IPCC

2nd Energy Transition report: CCS could address 62% of global CO2 emissions

www.rystadenergy.com

Rystad Energy has initiated a monthly Energy Transition Report which will analyse energy technology developments.

The assessment shows that CCS as a technology has the theoretical potential to address 62% (25 gigatonnes, GT) of global CO2 emissions, but net-negative technologies such as Direct Air Capture (DAC) and Bio Energy CCS (BECCS) will be needed given that traditional CCS has a capture rate of up to approximately 90%. However, it is unlikely that CCS will ever reach this level.

The current portfolio of operational CCS projects captures roughly 40 megatonnes (Mt) per year; if we include the upcoming project pipeline, this number increases to 110 Mt per year for projects that are to come online by the end of 2026.

These numbers compare to the IEA's Sustainable Development Scenario, with 5.6 Gt captured in 2050, representing a 50x increase from the current pipeline. To capture the total addressable market would require an additional 4x increase above the IEA SDS scenario.

"Where we end up will rely heavily on the development in carbon prices, which today are far below the levels needed to support most applications of CCS. The exceptions are perhaps in some European countries and some states in the US, which utilize a combination of emissions trading systems (ETS), carbon tax, carbon credits, or more direct subsidy schemes," says Marius Foss, senior vice president and head of global energy systems at Rystad Energy.

*When it comes to total greenhouse gas emissions (GHG), CCS could theoretically address up to 48% of the world's total, an upwards revision of our last general energy transition report that adds some more industrial GHG emissions.

Svante raises $75 Million to decarbonize cement and hydrogen production

svanteinc.com

Svante has successfully closed a $75 million equity financing, the largest private investment into point source carbon capture globally to date.

The financing was led by Temasek and includes strategic investors Chart Industries, Carbon Direct and Export Development Canada (EDC). Existing investors OGCI Climate Investments, BDC Cleantech Practice, Chevron Technology Ventures, The Roda Group and Chrysalix Venture Capital also participated in the round, reflecting strong on-going support for the Company, including its market strategy and recent progress.

This USD$75 million of new financing provides the Company with growth capital to advance a number of initiatives over the next three years, including work to support several commercial scale carbon capture facilities to address hard-to-abate emissions from industrial operations (such as cement manufacturing, blue hydrogen production and natural gas boilers).

Svante has now attracted more than USD$150 million in funding since it was founded in 2007 to develop and commercialize its breakthrough solid sorbent technology at half the capital cost of traditional engineered solutions.

“Lowering the capital cost of the capture of the CO2 emitted in industrial production is critical to the world’s net-zero carbon goals required to stabilize the climate,” said Claude Letourneau, President CEO of Svante Inc.

“Leaders from industry, financial sectors and government agree on the enormity of the challenge and the critical need to deploy carbon capture and carbon removal solutions at Gigatons scale. The carbon pulled from earth as fossil fuel needs to go back into the earth in safe CO2 storage.”

“The success of our financing is further evidence that Svante’s innovative solution is well positioned to address these challenges in the near term. We are proud that Temasek and a group of new strategic investors have demonstrated their confidence in Svante to play a key role in building a commercially viable CO2 marketplace.”

Elkem studying CCS opportunities with Aker Carbon Capture and Saipem

www.elkem.com

Elkem is conducting a feasibility study for the establishment of carbon capture at its Norwegian smelters.

Elkem, one of the world's leading suppliers of silicon-based advanced materials, has a broad and comprehensive approach to the work of reducing emissions and contributing to a sustainable future. Recently, the company was rated among the world’s leading on climate transparency and action by CDP.

As a part of this work towards carbon-neutral materials production, Elkem is currently conducting a feasibility study for the establishment of carbon capture and storage (CCS). The purpose of the study is to assess the technical and economic feasibility of installing carbon capture at its Norwegian plants in Bjølvefossen, Bremanger, Rana, Salten and Thamshavn. The project has received financial support from Gassnova, the Norwegian state enterprise to further develop technologies, through the CLIMIT program. The findings from the study will be transferred to Elkem’s plants outside Norway, including Elkem’s ferrosilicon plant on Iceland.

In connection with the study, Elkem has signed agreements with Aker Carbon Capture and Saipem. Together with these partners, Elkem will evaluate and study the different technological designs and solutions of a capture facility, facilities for liquefaction and upload of CO2 to transport ships from the Northern Lights project.

The carbon capture study will be completed in the second quarter 2021.

The independent Norwegian research organisation SINTEF and Norwegian consultancy corporation Norsk Energi will contribute as competence partners.

In addition to the opportunities within carbon capture and storage, Elkem is also studying alternatives for carbon capture and utilization, to combine storage and utilization in the future.

Elkem is also a part of CO2 Hub Nordland, a project gathering the process industry in Nordland, Norway with a goal to capture more than 1,2 million tons of CO2 annually. The CO2 hub Nordland project is supported by Gassnova.

Schlumberger, Chevron and Microsoft collaborate on BECCS

www.slb.com
www.chevron.com

The companies will jointly develop a bioenergy with carbon capture and sequestration (BECCS) project designed to produce carbon negative power in Mendota, California.

The BECCS plant will convert agricultural waste biomass, such as almond trees, into a renewable synthesis gas that will be mixed with oxygen in a combustor to generate electricity. More than 99% of the carbon from the BECCS process is expected to be captured for permanent storage by injecting carbon dioxide (CO2) underground into nearby deep geologic formations.

By using biomass fuel that consumes CO2 over its lifetime to produce power and then safely and permanently storing the produced CO2, the process is designed to result in net-negative carbon emissions, effectively removing greenhouse gas from the atmosphere. The plant, when completed, is expected to remove about 300,000 tons of CO2 annually, which is equivalent to the emissions from electricity use of more than 65,000 U.S. homes.

“We are excited to welcome Chevron and Microsoft on this exciting opportunity, as it further demonstrates how we play an enabling role to deploy carbon capture and sequestration solutions at scale,” said Ashok Belani, Schlumberger New Energy executive vice president. “We are diversifying our portfolio of projects with partnerships in selected markets and geographies where existing policies and regulations can make projects attractive today.”

The completed facility will help improve air quality in the Central Valley by using approximately 200,000 tons of agricultural waste annually, in line with the recent California Air Resources Control Board plan to begin phasing out almost all agricultural burning in the Valley by 2025. The bioenergy technology is designed to operate without routine emissions of nitrous oxide, carbon monoxide and particulates from combustion produced by conventional biomass plants.

The companies involved expect to begin front end engineering and design immediately, leading to a final investment decision in 2022, and will then evaluate other opportunities to scale this carbon capture and sequestration solution.

O.C.O Technology working on new mineralisation opportunities

Having comercialised a versatile process that uses carbon dioxide as a resource to treat a wide range of wastes while permanently capturing the CO2, O.C.O. Technology is now working on a trial with Mitsubishi on the carbonation of slag waste from a steel processing plant.

UK-based O.C.O Technology is used to achieving world-firsts.

It has led the way in commercialising its Accelerated Carbonation Technology (ACT) process, treating Air Pollution Control residues (APCr) from the Energy from Waste (EfW) sector with waste carbon dioxide gas to enable the permanent capture of significant amounts of CO2.

It was the first to manufacture a truly carbon negative artificial aggregate – known as Manufactured LimeStone (M-LS) – on a commercial scale, and its success has been such that in 2011, the UK's Environment Agency granted the product End of Waste (EoW) approval. It was the first time any company in Europe had achieved such an accolade for an APCr waste stream and secured the aggregate's position as a perfect example of the circular economy in action.

Last year, O.C.O produced over 310,000 tonnes of carbon negative aggregate from its three UK operations in Leeds, Avonmouth and Suffolk, a figure that continues to grow as the construction industry seeks to improve its sustainability credentials.

The benefits of Manufactured LimeStone

O.C.O's M-LS is already in demand as a sustainable building material. In 2019, it was estimated that its M-LS BlockMix, specially formulated for use in concrete masonry blocks, was used in well over 25 million blocks – the equivalent to building more than 10,000 three-bedroom homes.

Key benefits:

- Enables capture of significant volumes of CO2
- Demonstrates the circular economy in action
- Contributes to sustainable construction products
- Diverts APCr and other residues from landfill
- Every tonne of M-LS used avoids the quarrying of 1.4 tonnes of natural aggregate

Now however, as the world turns up the heat on the drive towards net zero emissions, O.C.O is using its same proven expertise in carbon capture and the mineralisation of CO2 to look at the potential carbonation of other forms of waste.

To help facilitate this, the company recently secured permit variations at all three of its sites to enable it to handle different types of waste and increase the range of materials authorised for processing.

Carbon negative M-LS aggregate from O.C.O Technology is in demand as a sustainable building material

In early February, trials began at its main R&D laboratory on the carbonation of slag waste from steel processing plants, an innovative new project it is working on with Japan's Mitsubishi Corporation.

It is part of a wider project with Mitsubishi Corporation to assess the opportunity for carbonating new waste materials, and comes after the Japanese giant chose O.C.O as one of only four global companies – and the only one in the UK – to join its Green Concrete Consortium.

Billed as a combination of carbon capture and utilisation (CCU) mineralisation projects, the Consortium's goal is to transform CO2 into carbon negative concrete and aggregates, a move which is enabling the O.C.O team to ramp up development of its technology.

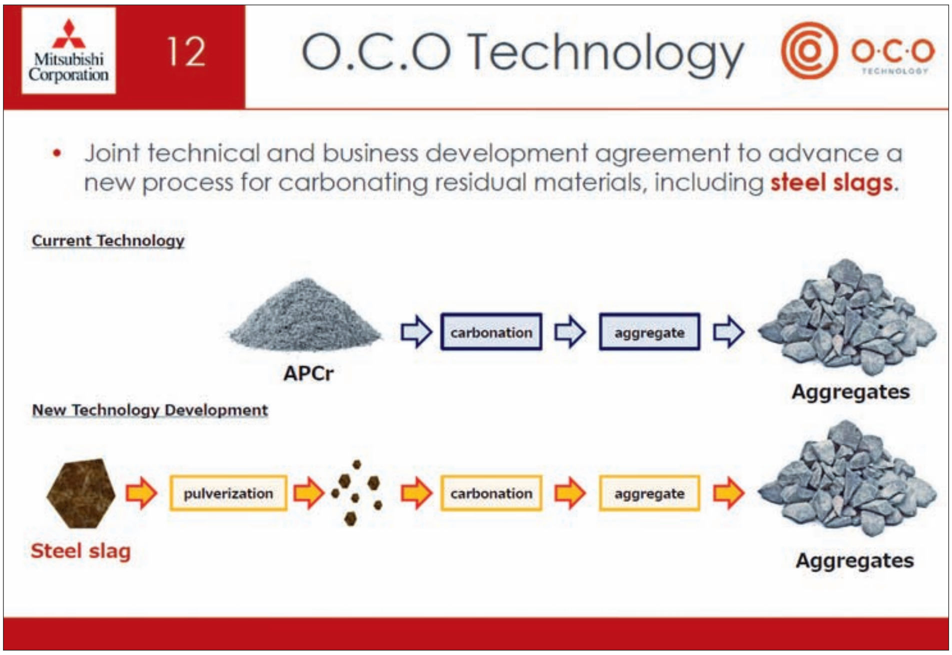
Potential to lock in 140m tonnes of CO2

Dr Peter Gunning, O.C.O's Head of Research & Development, said: "Partnering with Mitsubishi is a fantastic opportunity and gives us the perfect platform to demonstrate the role that carbon capture, through the mineralisation of CO2, can play in combating climate change.

"Around the world, if you look at the materials available to apply this technology, the potential is enormous. Given that just energy recovery, metallurgical processes (such as steel production), biomass, cement manufacture and paper production – produce waste arisings of more than 1 billion tonnes, with the potential to lock in a staggering 240 million tonnes of carbon dioxide. That is a very big number indeed. And there is more potential in other wastes besides".

"There are many carbon-friendly innovative technologies and ideas out there that will hopefully come to fruition. We have the advantage in that our process is tried and tested – we are mineralising the CO2 into solid carbonate and turning it into a stable, solid product that guarantees the carbon remains locked in.

"To our knowledge, although there are other pilot projects working on carbon mineralisation, we don't believe there is anyone else operating commercially on such a large scale as us, and the potential for the new materials we are working on is huge."



The current technology for producing the M-LS from APCr and how the carbonation process will work for steel slag waste – credit Mitsubishi Corporation

Testing

The Japan project combines the expertise of both O.C.O and Mitsubishi Corporation (MC) with another Japanese engineering firm. Work began in 2020 and over the last six months laboratory trials have been taking place in Japan to prepare samples of the slag for the carbonation process.

With the arrival of those samples in the UK, trials are now under way at the main R&D laboratory to understand performance levels and gauge the carbonation potential.

Dr Gunning continues: "This is a very exciting stage of the project, no two materials are alike and of course, this is the first time we have worked with this material, so these tests are critical to the next steps.

"Our ACT process combines the slag with waste CO2 gas and a blend of binders and fillers to create the M-LS. It's much like baking the perfect cake, tweaking the recipe until we have got it just right. Making sure we can meet the rigorous End of Waste specifications."

Once the UK trials are complete, the samples will be sent back to Japan for further chemical and aggregate testing, with the eventual aim of commercialising the process in the same way O.C.O has done for its APCr carbon negative aggregates.

The partnership has been praised by Masao Koyama, manager of Mitsubishi Corporation's Carbon Capture and Utilization (CCU) task force, who says: "We are passionate to work with O.C.O Technology, a company who owns one of the most competitive carbon removal technologies to capture CO2 into waste materials.

"We will continue supporting O.C.O and the project to gather market information and to assist the business development, utilising our global network and knowledge from our existing business including other CCU activities. We are excited to be part of a great partnership which we strongly believe will contribute to prevent our biggest problem climate change."

O.C.O's links with Mitsubishi Corporation have also gone one step further as, in a joint partnership with carbon project developer South Pole, its carbon capture technology has been submitted in response to Microsoft's Request for Proposals (RFP) as the technology giant searches for carbon removal projects.

If the proposal by South Pole is successful, it is hoped that O.C.O's Leeds facility will become a recognised carbon credit offset option for Microsoft. The verification procedures for the Microsoft bid, together with yet to be announced new initiatives in carbon credit trading, will allow the Mitsubishi Corporation / South Pole / O.C.O partnership to offer carbon credits to other companies keen to offset their carbon emissions.

Biomass APCr

Closer to home, O.C.O has been extending its reach into the biomass sector.

In 2020, the company began working with Tilbury Green Power (TGP), which wanted to find a circular economy solution for APCr from its waste wood powered renewable energy facility.

Previously, O.C.O had been predominantly using its technology in the municipal waste EfW sector, where customers include Grundon Waste Management, Viridor, and the Ferrybridge Multifuel 2 (FM2) power station in Yorkshire operated by SSE.

But because biomass APCr has different characteristics to municipal waste EfW APCr, O.C.O's in-house team of chemists needed to carry out rigorous trials to ensure the aggregate would still be 100% compliant with the End of Waste specification.

Dr Gunning says it is just one example of how the company's track record of expertise and experience enables it to respond quickly and effectively to new challenges within the marketplace.

In 2019, the equivalent of 11,695 tonnes of M-LS was made with biomass APCr and in 2020 that had more than doubled to 24,090 tonnes – around 6.5% of the total waste O.C.O handles annually.

Dr Peter Gunning is pictured in the laboratory at O.C.O Technology's Avonmouth facility

A more 'harmonised' approach is needed to EoW

Alongside its work in Japan, O.C.O is also working on projects in Australia and, with an increased focus on utilising carbon capture technologies to help meet carbon zero targets worldwide, Dr Gunning says he feels real hope for the future.

"Today's younger generation understand far more about recycling and reuse of materials but I believe a wider change is needed on a global scale," he said.

"We are now beginning to see governments unlocking more funding for carbon friendly technologies and I would like to see more of that happening at a faster pace. However, that must come hand-in-hand with a more forward-thinking approach towards the development of End of Waste mechanisms and the certification of products valorised from waste".

"There can still be a perception that products derived from waste are in some way inferior and that needs addressing – it is improving – but while some countries have embraced the concept of the circular economy and End of Waste certification, others are still inclined to dismiss it completely or haven't yet implemented the mechanics to make it happen.

"I believe the UK's Environment Agency has been at the front of the EoW curve. We have this fantastic proven technology at our fingertips, but it's not as simple as taking that portfolio of information and giving it to the necessary authorities in other countries – you have to start the process all over again.

"Right now, regulation is the biggest sticking point, if we can get to a more harmonised approach with a wider recognition of a global market for these technologies and the huge potential for carbon capture in the fight against climate change, then we can all truly make a difference."

More information

www.oco.co.uk

Lowering carbon emissions with cost-effective investments

Marcel Suhner, Global Product and Application Management (Mixers, Power, Carbon Capture) - Technology Management and Process Innovation at Sulzer, looks at what to consider when selecting separation technologies for carbon sequestration.

What to look for when selecting carbon sequestration technologies

Successful carbon capture utilization and storage (CCUS) solutions need to be able to sequestrate large volumes of carbon dioxide (CO2) while being energy- and cost-efficient. To implement effective systems, businesses should select the right extraction technologies that can address these fundamental requirements. By doing so, it is possible to increase the sustainability of industrial activities while maintaining low capital expenditure (CAPEX) and operational expenses (OPEX).

Stationary sources of CO2 emissions, such as power plants and manufacturing facilities, are estimated to be responsible for 50-60% of total global emissions. These can be considerably reduced, as businesses operating these sites can benefit from well-established CCUS post-conversion – also known as post-combustion in power plants – solutions to reduce the environmental footprint of their activities.

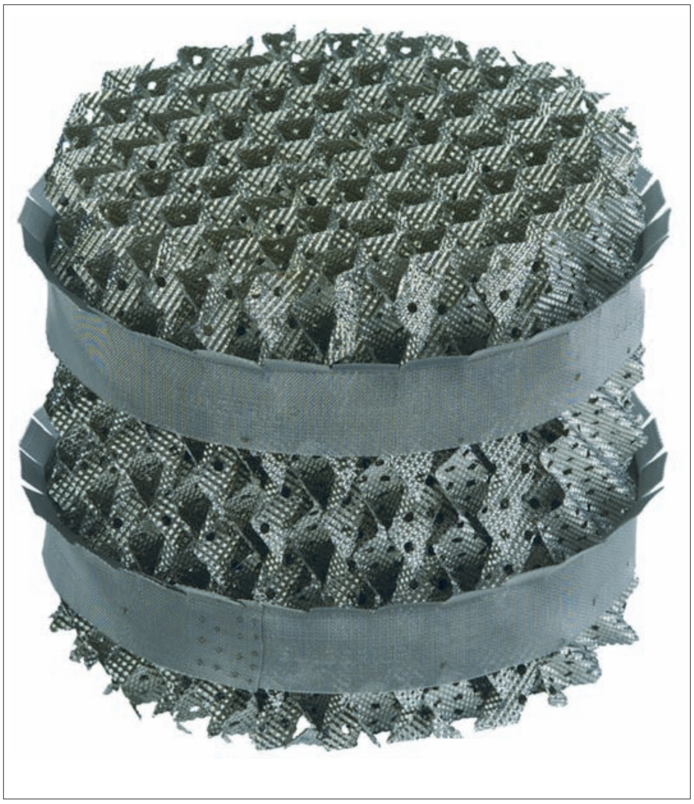
More precisely, lifecycle assessments indicate that the global warming potential of power plants can be reduced by 63–82% per unit of electricity generated. For example, while a conventional combined cycle gas turbine plant is likely to produce 471 kg CO2 eq./MWh, it is estimated to generate only 173 kg CO2 eq./MWh when post-combustion CCUS systems are in place[1].

One of the key benefits of post-combustion CCUS solutions is that they can be added to existing infrastructures as part of retrofit projects. Therefore, businesses do not need to build new plants to improve their sustainability.

Most of the large-scale, commercial CCUS projects that are currently operational, rely on an amine-based gas sweetening treatment, known as the amine scrubbing process, patented by Bottoms in 1930. This involves a fast-reaction regime that promotes the chemical absorption of CO2 onto amine-based solvents, such as monoethanolamine or methyldiethanolamine, from methane or flue gases. The most common setup for such a method consists of an absorber column followed by a regenerator, or stripper, unit.

The CO2-rich flue gases enter the bottom of the absorber and make contact with a down-flowing liquid amine-based solvent throughout the column. CO2 is absorbed through a reversible exothermic reaction, while the flue gases are released to the atmosphere.

The solvent containing the CO2, or rich solvent, exits at the bottom of the absorber and is sent to a stripping column, which reverses the absorption reaction. After the desorption process, the CO2 released from the stripper is compressed for storage or utilization, while the lean solvent is recycled to the top of the absorber column for reuse.



Sulzer MellapakCC™ Structured Packing is an example of a structured packing solution developed specifically for post-combustion CO2 capture

Separation at its best

While existing post-combustion facilities share this same principle, they greatly vary in terms of performance, yield, energy efficiency and costs. In effect, separation equipment needs to be customized to an application to ensure effective post-combustion, amine-based CO2 absorption and desorption processes.

One of the first elements to look at is ensuring most of the solvent is recovered and not emitted with the flue gases. This is essential to reducing OPEX as well as creating a sustainable system that minimizes the use of amine-based chemicals and meets ever more ambitious environmental regulations. A highly effective strategy consists of including

1. *Cuéllar-Franca, R. M., & Azapagic, A. (2015). Carbon capture, storage and utilisation technologies: A critical analysis and comparison of their life cycle environmental impacts. Journal of CO2 utilization, 9, 82-102.*

washbed pumparounds, such as Sulzer's AY-Plus™ DC, with specific liquid distributors above the absorption section.

These can effectively reduce solvent emissions well below the ppm level.

Another important aspect to consider is energy efficiency. Carbon capture can turn into a highly energy-intensive process, as CO2 is generally present at low concentrations, typically between 3.5 vol% and 14 vol%, in gaseous streams that are generated in high volumes. For instance, an 800 MW coal-fired power plant can emit up to 3 million m3 of flue gases per hour. Also, the desorption phase requires elevated temperatures that substantially increase the energy requirements.

Therefore, it is crucial to utilize a setup that can minimize energy usage. By doing so, it is possible to create a truly sustainable and cost-effective process. In power plants, this also maximizes the net electrical output, increasing profit and revenue.

To implement an energy-efficient CCUS process train, businesses should first look at heat integration solutions. By incorporating reboilers and/or reclaimers, it is possible to create a circular system that reuses the steam generated for the entire power plant.

The need for structured packing

The energy requirement of amine scrubbing activities is also determined by the type of packing and internals that are used. More precisely, structured packing should be preferred. When compared to trays, it allows for the design of smaller, economical columns by accommodating a high number of theoretical stages.

Thanks to its ability to support high throughput and capacity, this packing also reduces the risk of flooding. Furthermore, structured packed CO2 absorbers and strippers feature minimal pressure drops, lowering energy consumption and OPEX while increasing the overall system performance. Besides, structured solutions tend to be lighter, thus offering low CAPEX.

To further improve energy-, cost- and separation efficiency, businesses should look for structured packing that has been specifically developed to address the need of CCUS systems. Solutions made of resistant materials should be favored, as the amine-based solvents, CO2 and oxygen can corrode the column components. This reduces maintenance requirements and aligns with the typical operational lifespan of power plants, which can exceed 30 years.

In addition, the technology used should maximize mass transfer efficiency and hydraulic performance. This means increasing the effective interfacial area, or wetted area, while maintaining low pressure drops. When looking at the geometry of structured packings, solutions with low specific areas are ideal, as they exhibit a more complete wetting characteristic than systems with higher specific areas. Ultimately, this leads to a more effective utilization of the installed metal area and a reduction in the overall CAPEX.

Solutions designed with CCUS needs in mind

An example of a structured packing solution developed specifically for post-combustion CO2 capture is Sulzer's MellapakCC™, which is currently used by different CCUS projects in coal-powered plants. This technology was designed to further reduce column size, pressure drop and flooding in CO2 absorbers, thus reducing CAPEX and OPEX.

Further to this, when compared to conventional structured packing, MellapakCC™ has been proven to increase efficiency by 20%, as well as lowering pressure drop by a minimum of 20% and up to 50-60%, even as the F-factor increases. Also, the packing height required to deliver at least the same performance of traditional systems can be 20% smaller, contributing to even more savings in CAPEX.

In addition to conventional post-combustion amine-based scrubbing in power plants, MellapakCC™ has also been used for CO2 removal in a number of different manufacturing sectors, such as liquified natural gas (LNG) and fertilizer production facilities. In these applications, pressure drop is generally limited in the absorber unit, while it is necessary to accommodate particularly high gas or liquid loads and high-pressure conditions.

Sulzer's MellapakCC™ is also able to address these requirements. In particular, when used in place of random packing in carbon capture facilities, it can support 40-70% higher gas loads in absorbers operating at 80% hydraulic capacity at LNG plants. Furthermore, by replacing random packing with Sulzer's specific structured packing, the units can considerably increase their capacity while maintaining the same footprint.

Successfully implement CCUS projects

CCUS facilities in manufacturing, power, steel and cement plants are becoming essential to meet key environmental goals. These do not need to be costly and energy intensive. By selecting an expert technology partner, such as Sulzer, and advanced, reliable solutions developed to address the needs of carbon sequestration activities, businesses can benefit from highly effective setups.

These require low CAPEX, OPEX and energy to run their processes, allowing companies to potentially increase their competitiveness while meeting sustainability goals. CC

More information

www.sulzer.com

SMR ♥ CLC = the perfect match for blue hydrogen?

By combining Steam Methane Reforming with Chemical-Looping Combustion, SMR-CLC, it should be possible to produce hydrogen from natural gas and capture CO2 with higher energy efficiency than conventional SMR. By Professor Anders Lyngfelt, Chalmers University of Technology

The need for zero-emission fuels in combination with large resources of natural gas has raised the interest in blue hydrogen. However, blue hydrogen comes with the well-known issues of CO2 capture, i.e. the cost and energy penalty of CO2 separation.

Moreover, CO2 separation becomes significantly more costly if the all the CO2 needs to be captured, which is why conventional capture typically stops at around 90%. But will this be enough, when the rapidly dwindling carbon budgets indicate we need to reach zero emissions?

Today, the most common way to produce hydrogen is steam-methane reforming, SMR, of natural gas. The major constituent of natural gas is methane, CH4, and the name of the process refers to the key reaction, the heat-demanding reaction between steam and methane to produce a syngas, consisting of CO, H2, CO2, H2O and some unreacted CH4, Figure 1.

In a subsequent process step called water-gas shift, WGS, the hydrogen content is increased by the reaction of H2O with CO, giving H2 and CO2. The hydrogen can be extracted from the gas using pressure swing adsorption, PSA, providing high purity hydrogen. The remaining off-gas is burnt together with additional natural gas to provide the heat needed for the steam-methane reforming process.

The flue gas from burning off-gas needs to be stripped of CO2 in order to achieve a CO2-free hydrogen. It should be said that a part of the CO2 can be captured upstream of the combustion, i.e. from the flows going into and out of the PSA step.

The steam-methane reforming takes place in long tubes filled with catalyst where the inside gas temperature may vary from around 600 to 900°C, with the heat provided by radiation from high-temperature flames outside the tubes. To achieve sufficient heat transfer the temperature of the gases leaving the furnace is high, typically around 1200°C, which means that the major part of the heat produced by the combustion leaves the furnace instead of being utilized for the steam-methane reforming.

The locally high temperatures of flames in combination with a varying gas temperature and heat consumption inside the tubes means that the tubes are exposed to harsh conditions, and local hot spots may cause damage to the expensive tubes and catalyst.

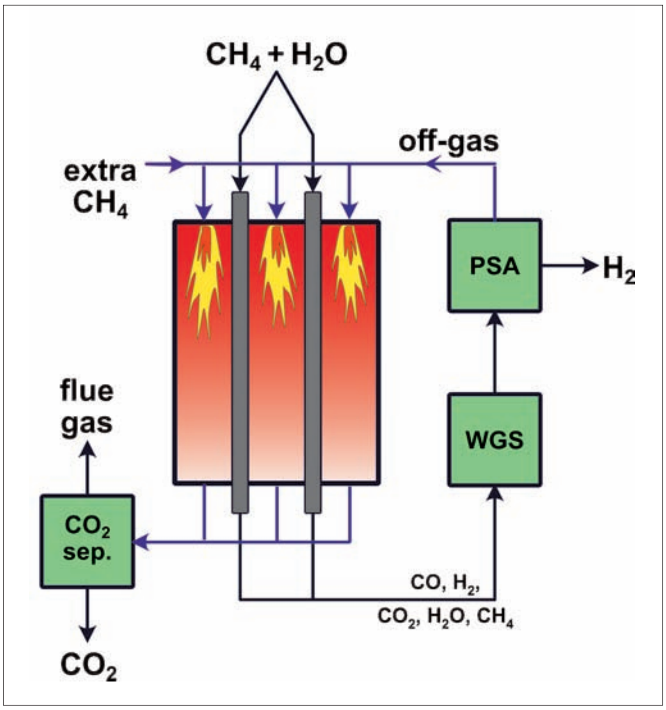


Figure 1. SMR, Steam-Methane Reforming with CO2 capture

Chemical-Looping Combustion, CLC, is a process where the oxygen is transferred from the air to the fuel using an oxygen carrier, circulating between the air reactor and the fuel reactor, Figure 2. Ideally, the exhaust from the fuel reactor only contains CO2 and H2O, the latter easily removed by condensation.

Thus, pure CO2 can be obtained without any costly and energy demanding gas separation. This is because the combustion is accomplished without the air meeting with the fuel. The exhaust from the air reactor is just air which has lost most of its oxygen content.

Similar to circulating fluidized-bed combustion, FBC, and fluidized catalytic cracking, FCC, the chemical-looping process uses fluidized-bed technology, albeit with the oxygen carrier as bed material. The air reactor, having the major gas flow, can be used as a riser to drive the circulation between the two reactors, and loop-seals fluidized by steam can be used to prevent any mixing of gas between the air and fuel reactor.

If the high temperature furnace used for burning off-gas and methane for heating the steam reforming tubes is replaced by chemical-looping combustion, CO2 can be captured without a costly and energy demanding gas separation process, Figure 3.

An additional advantage with SMR-CLC is that the heat can be transferred to the steam reforming tubes using fluidized-bed heat exchangers, FBHE, with high heat transfer and low excess temperature. Thus, the temperature of the outgoing flue gases can be reduced from 1200 to 935C, which means that a significantly higher proportion of the combustion heat is used for heating of the steam-methane reforming reaction [1]. Thus, not only is the energy penalty of CO2 capture avoided, furthermore the energy efficiency can be increased at the same time as CO2 is captured. This is likely the only CO2 capture process with raised energy efficiency. To be fair, this is true for the capture of CO2, but transport and storage also requires pressurized CO2.

A further advantage is that CLC-SMR can eliminate NOx emissions. Firstly no thermal NOx is formed in the air reactor because of the low temperature and the absence of flames. Secondly, the absence of any nitrogen compounds other than N2 in the natural gas will also prevent the formation of fuel-NOx in the fuel reactor.

But does it work? Although no full-scale applications have been built, there is significant experience from around 50 smaller CLC pilots of 0.3 kW to 3 MW, with a total operational experience nearing 12,000h, using around a hundred different oxygen carrier materials for burning gaseous, solid and liquid fuels [2].

Methane is the most difficult molecule to oxidize in chemical-looping combustion of off-gas. Early work on chemical-looping focused on oxygen carriers based on nickel oxide, which has high reactivity towards methane. Unfortunately, nickel oxide is quite expensive, comes with health and safety issues, and is not able to give full gas conversion because of thermodynamic constraints. Since then, however, novel combined manganese oxides with the ability to release gas phase oxygen have been developed. Thus, pilot operation has verified that full conversion of natural gas with a slight excess of oxygen can be reached with calcium manganite, [3].

The material can be manufactured from low cost manganese ore and limestone and pilot operation verifies that materials with high mechanical and chemical integrity can be produced. Moreover, these materials are environmentally benign and any fines formed by attrition can be recovered and used for production of new oxygen carrier, provided that the natural gas is free of ash.

Both pilot operation and modelling indicate that the solids inventory needed to achieve full conversion is viable [4, 5].

Thus, by combining Steam Methane Reforming with Chemical-Looping Combustion, SMR-CLC, it should be possible to:

• produce hydrogen from natural gas and capture CO2, with higher energy efficiency (not counting the CO2 compression) than conventional SMR

• avoid costs of CO2 separation

• avoid difficulties with high temperatures in SMR

• capture 100% of the carbon

• eliminate NOx emissions

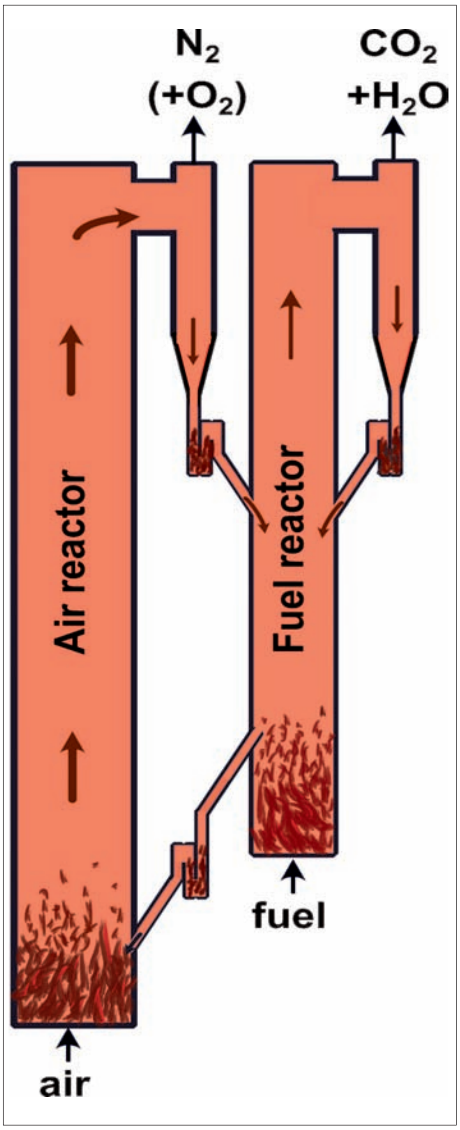


Figure 2. Example of a CLC reactor system

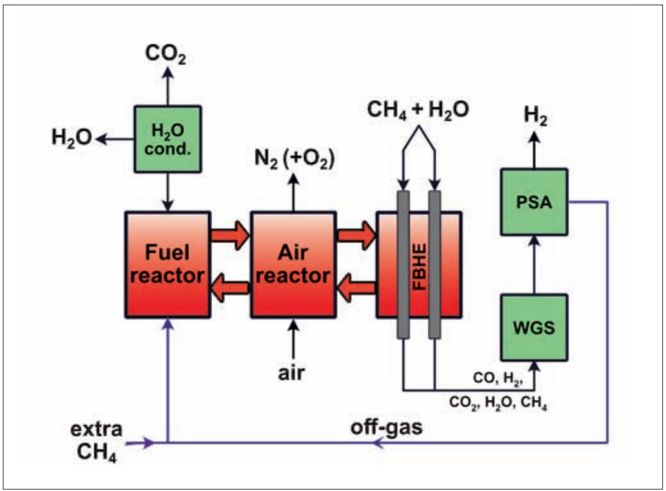


Figure 3. SMR-CLC, Steam-Methane Reforming and Chemical-Looping Combustion

References

[1] Stenberg V, Spallina V, Mattisson T, and M. R. Techno-economic analysis of H2 production processes using fluidized bed heat exchangers with steam reforming – Part 2: Chemical-looping combustion. Accepted for publication w. minor revisions (2021).

[2] Lyngfelt A. Chemical Looping Combustion: Status and Development Challenges. Energy Fuels 34 (2020) 9077–9093.

[3] Källén M, Rydén M, Dueso C, Mattisson T, and Lyngfelt A. CaMn0.9Mg0.1O3-δ as Oxygen Carrier in a Gas-Fired 10 kWth Chemical-Looping Combustion Unit. Industrial & Engineering Chemistry Research 52 (2013) 6923-6932.

[4] Mayer K, Piesenberger S, Penthor S, Pröll T, and Hofbauer H. Chemical Looping Combustion Using Two Different Perovskite Based Oxygen Carriers: A Pilot Study. Energy Technology (2018) 2333 – 2343.

[5] A. Abad, A. Cabello, P. Gayán, F. García-Labiano, L.F. de Diego, T. Mendiara, and Adánez J. Kinetics of CaMn0.775Ti0.125Mg0.1O2.9-δ perovskite prepared at industrial scale and its implication on the performance of chemical looping combustion of methane. Chemical Engineering Journal 394 (2020) 124863.

More information

www.entek.chalmers.se/lyngfelt

Capture and utilisation news

LafargeHolcim and Schlumberger New Energy join for CCS project

www.slb.com

www.LafargeHolcim.com

The two companies will study the feasibility of capturing carbon from two LafargeHolcim cement plants, based in Europe and North America, using Schlumberger's carbon sequestration technologies.

Schlumberger said the collaboration is a step towards developing a blueprint for large-scale deployment of Carbon Capture and Storage solutions in transformational sectors and that Schlumberger New Energy is partnering with leaders in a range of strategic sectors to demonstrate carbon solutions across a wide range of projects.

Ashok Belani, Executive Vice President, Schlumberger New Energy, commented, “Partnering with LafargeHolcim is a unique opportunity to work collaboratively and demonstrate that Carbon Capture and Storage can be done safely and at scale.”

“We are quickly expanding our Schlumberger New Energy activities via strategic partnerships across several industrial sectors. This collaboration is an example of an innovative model that joins the world’s global leader in building solutions and the subsurface domain expert to cover all aspects of the Carbon Capture and Storage value chain.”

LafargeHolcim said it is piloting more than twenty Carbon Capture projects across Europe and North America to identify the most promising ventures with scale-up potential.

Kobe Steel verifies CO2 reduction process

www.kobelco.co.jp/english

The results indicate that the technology can reduce CO2 emissions from blast furnaces by approximately 20% compared to a conventional method.

Kobe Steel has successfully demonstrated a technology that can reduce a significant amount of CO2 emissions from blast furnace operations. The demonstration test was conducted for a month at a large blast furnace (4,844 m3) of the Kakogawa Works in Hyogo Prefecture, Japan in October 2020.

The quantity of CO2 emissions from the blast furnace is determined by the reducing agent rate (RAR) or the quantity of carbon fuel used in blast furnace ironmaking. In the demonstration test, it was verified that RAR could be stably reduced from 518 kg/tHM (ton hot metal) to 415 kg/tHM by charging a large amount of hot briquetted iron (HBI) produced by the MIDREX® Process. The results indicate that this technology can reduce CO2 emissions by approximately 20% compared to a conventional method.

In addition, the world's lowest level of coke rate (239 kg/tHM) has been achieved in the demonstration test of this technology. The company sees it as a promising solution that could become readily available in the near future at a lower additional cost compared to other CO2 reduction measures.

ll of these technologies are developed by the KOBELCO Group as generic solution technologies applicable to various blast furnaces.

"We will keep improving this CO2 reduction solution technology while further reducing CO2 emissions and achieving lower costs for CO2 reduction," said the company. "Beyond our own efforts to reduce emissions from our facilities, we will strive to contribute to the acceleration of CO2 reduction through introducing this solution to blast furnaces around the world."

"In addition, we believe that the success of the demonstration test on an actual blast furnace has made a significant step forward in providing low CO2 steel products to customers."

Veolia and Carbon Clean to start first carbon capture trials in UK Energy Recovery Facilities

www.veolia.com

www.carbonclean.com

The companies have been working in partnership for four years, and the new joint project will investigate how the technology can work effectively on Energy from Waste (EfW) plants.

Teams from the partnership have already started work on the project with the trial estimated to start during Spring 2021.

Gavin Graveson, Executive Vice President of UK and Ireland said, "This project marks another significant step forward for the industry by making it possible for Energy Recovery Facilities to contribute to the environment through lowering carbon and delivering landfill diversion, grid resilience, district heating and carbon capture. By using the potential of non recyclable waste to generate energy and support communities, we can power the low carbon cities of the future."

Veolia currently operates ten UK plants that take around 2.3 million tonnes of non-recyclable waste and transform this into electricity for over 430,000 homes.

This combined generating capacity of 180MWe takes pressure off the stretched UK electrical grid and effectively avoids using fossil fuels for generation. Some of these facilities also produce heating for communities through district heating networks, by using combined heat and power technology.

As an estimated 20% of the nation’s carbon emissions are generated by domestic heating, due to a low standard of energy efficiency, using this type of non - fossil fuel heating lowers carbon emissions and can help reduce cost, and fuel poverty, in vulnerable groups.

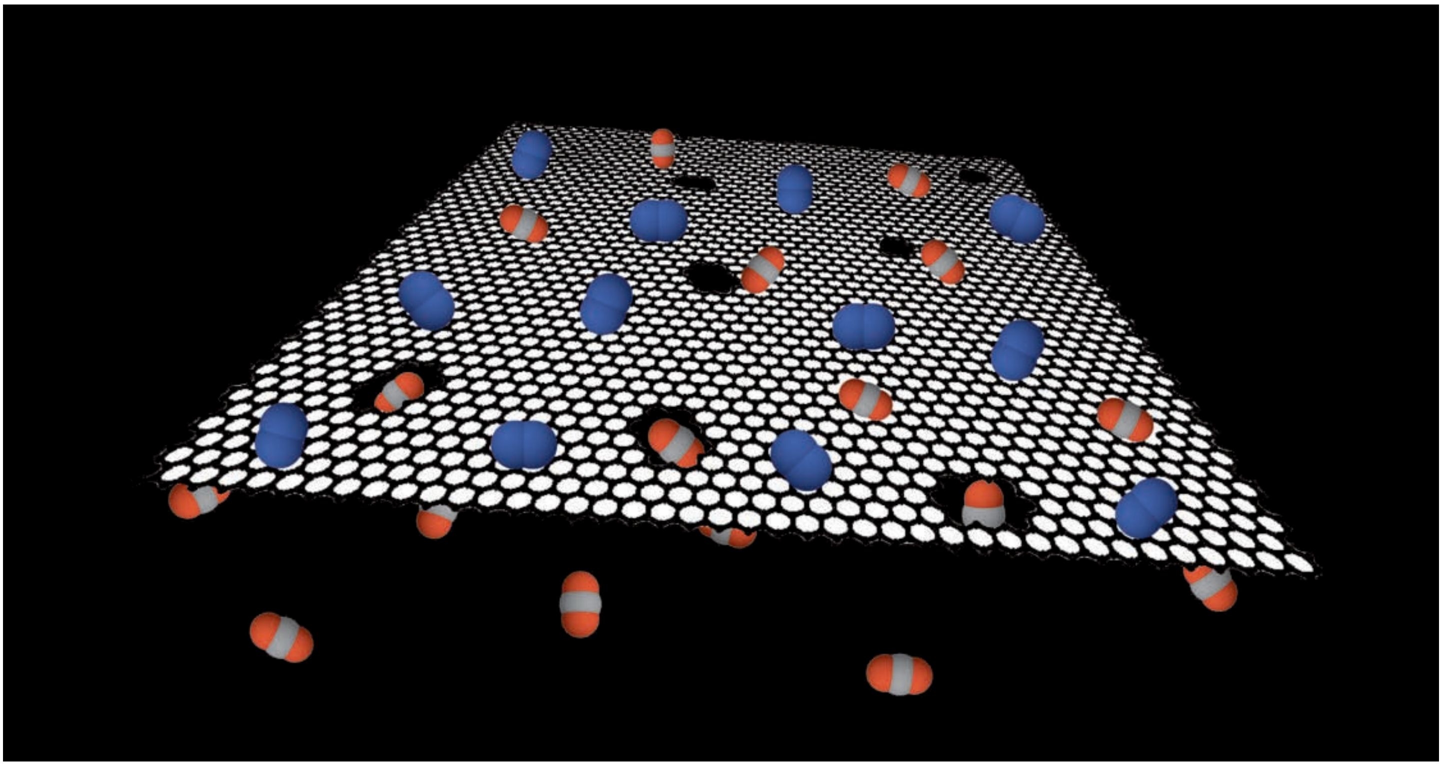
This latest Carbon Clean technology is significantly smaller than other technologies, making it suited to retrofit applications, such as ERF, and will extract and purify CO2 from combustion flue gas emissions into a valuable commodity that can form part of a new circular carbon economy.

A specific solvent has been developed to extract carbon dioxide from industrial gases with low energy input, and the CO2 is then compressed and/or liquified to be used in an industrial application or for permanent storage.

Potential applications for the captured carbon include: use in greenhouses to boost plant growth, building materials such as concrete, production of organic chemicals that make up solvents, synthetic rubber, and plastics. Other uses cover creation of synthetic fuels and production of carbon materials such as graphene, carbon nanotubes, and carbon fibres.

Graphene filter makes carbon capture more efficient and cheaper

Chemical engineers at EPFL have developed a graphene filter for carbon capture that surpasses the efficiency of commercial capture technologies, and can reduce the cost carbon capture down to $30 per ton of carbon dioxide.



An illustration of the graphene carbon dioxide filter. Image: KV Agrawal, EPFL

Scientists have been trying to develop an energy-efficient carbon dioxide-filter. Referred to as a "membrane," this technology can extract carbon dioxide out of the gas mix, which can then be either stored or converted into useful chemicals.

"However, the performance of current carbon dioxide filters has been limited by the fundamental properties of currently available materials," explains Professor Kumar Varoon Agrawal at EPFL's School of Basic Sciences (EPFL Valais Wallis).

Now, Agrawal has led a team of chemical engineers to develop the world's thinnest filter from graphene, the world-famous "wonder material" that won the Physics Nobel in 2010. But the graphene filter isn't just the thinnest in the world, it can also separate carbon dioxide from a mix of gases such as those coming out of industrial emissions and do so with an efficiency and speed that surpasses most current filters. The work is published in Science Advances.

"Our approach was simple," says Agrawal. "We made carbon dioxide-sized holes in graphene, which allowed carbon dioxide to flow through while blocking other gases such as nitrogen, which are larger than carbon dioxide." The result is a record-high carbon dioxide-capture performance.

For comparison, current filters are required to exceed 1000 gas permeation units (GPUs), while their carbon-capturing specificity, referred to as their "carbon dioxide/nitrogenseparation factor" must be above 20. The membranes that the EPFL scientists developed show more than ten-fold higher carbon dioxidepermeance at 11,800 GPUs, while their separation factor stands at 22.5.

"We estimate that this technology will drop the cost of carbon capture close to $30 per ton of carbon dioxide, in contrast to commercial processes where the cost is two-to-four time higher," says Agrawal.

His team is now working on scaling up the process by developing a pilot plant demonstrator to capture 10 kg carbon dioxide per day, in a project funded by the Swiss government and Swiss industry.

More information

www.epfl.ch

Transport and storage news

CO2CRC launches technical advisory and consultancy

co2crc.com.au

CO2CRC has established a wholly-owned subsidiary company CO2Tech to provide a range of services and expertise.

"We have established CO2Tech to meet the growing customer need for multi-disciplinary technical consultation, advisory and project management services across the whole CCUS value chain." said Mr Byers.

CO2Tech will have access to the Otway International Test Centre (OITC) and CO2CRC's expertise via commercial agreements.

"CO2Tech will allow CO2CRC Limited to offer our industry partners and customers, tailored solutions while preserving commercial confidentiality.

"CO2Tech will be pleased to work with industry customers to help them achieve their emissions reductions goals by applying individualised technologies and techniques that result in lower costs for capturing, storing or utilising CO2."

"It is an exciting era for CCUS at international, national and industry levels. CCUS has been identified as a priority technology under the government's Technology Investment Roadmap

"CO2CRC will continue to partner with world leading researchers, international industry and Australia Federal and State Governments to continue its traditional collaborative research model to advance the deployment of CCUS. This includes contributing to the achievement of the Australian Federal Government's long-term stretch goal for CCS ($20 per tonne for CO2 compression, transport and storage)." he said

Measurement needs to enable Carbon Capture, Usage and Storage

www.npl.co.uk

The National Physical Laboratory (NPL) report, 'Energy Transition: Measurement needs for carbon capture usage and storage,' outlines crucial measurement needs and challenges that will require addressing.

As the UK's National Metrology Institute, one of NPL's primary roles is understanding where measurement science can assist in supporting areas of growing interest to government and industry. NPL is working with government, industry and academia to ensure these needs and challenges are addressed whilst CCUS continues to gain momentum as a promising technology in the UK's energy transition.

The high priority measurement needs and challenges outlined in this latest report from NPL's Energy Transition series were identified through an industry-wide webinar series run by NPL and colleagues at TÜV SÜD National Engineering Laboratory, as well as in-depth consultation with key stakeholders across the CCUS industry and a comprehensive literature review.

Richard Barker, Head of Energy and Environment, NPL said, "Achieving net zero and limiting global temperature rise is a monumental task for society. Technological and socio-economic innovation in reducing emissions can get us far, but the end-goal can only be realised through carbon capture and long-term storage in one form or another."

"It has to work – there is no quick fix – which is why NPL is focusing on developing the science and quality system to assure we capture the carbon and can re-use or store it safely for the long term. We hope this report can stimulate all stakeholders in engaging, investing and assuring that CCUS does fulfil its role in achieving the UK ambition of net zero."

Subsea 7 Norway and Aibel win Northern Lights contracts

www.equinor.com

The contracts are for pipelaying and subsea installation and a subsea control system located on the Oseberg A platform.

"The new contracts in the Northern Lights project will create important activity for the supplier industry. Most contracts are now in place, and we look forward to working together with the selected suppliers to realise this pioneering project," says Peggy Krantz-Underland, Equinor's chief procurement officer.

Subsea 7 has won an EPCI (engineering, procurement, construction and installation) contract for pipelaying and subsea installations. The contract value is estimated at about NOK 500 million.

The supplier will fabricate and lay a 100 km long pipeline that will transport CO2 from the intermediate storage site at Energiparken in Øygarden to the injection well in the North Sea.

Subsea 7 will also install a 36 km long umbilical that will connect the injection well to the Oseberg field from which the subsea injection facilities will be operated.

Project management and engineering will be delivered by Subsea 7's office at Forus, while fabrication of pipes will be done at the Vigra spool base near Ålesund. The contract is expected to result in approximately 250 man-years during the project's life. Planning of the work will start immediately, and the main offshore operations are scheduled to be carried out during 2022-2023.

Aibel has been awarded an EPCI contract for the Northern Lights subsea control system located on the Oseberg A platform. The contract is awarded as a call-off against the existing Oseberg portfolio agreement signed in July 2020. The estimated value of the assignment is about NOK 140 million.

The scope of work includes all necessary upgrades on the Oseberg A platform to pull in and operate the umbilical system that will connect the platform and the Northern Lights subsea facilities.

Project management and engineering will be performed at Aibel's offices in Bergen and Stavanger, and prefabrication will take place at the Haugesund yard. The project will contribute with about 60 man-years for Aibel. The work will start in January 2021 and is planned to be completed late 2023.

"The Northern Lights project is the first of its kind offering a solution to cut emissions from industrial sources in Norway and Europe. Work has started at the site and with these two important contracts in place, we are ensuring that the project progresses according to plan in order to deliver a key part of the important Longship project," says Sverre Overå, project director of Northern Lights.

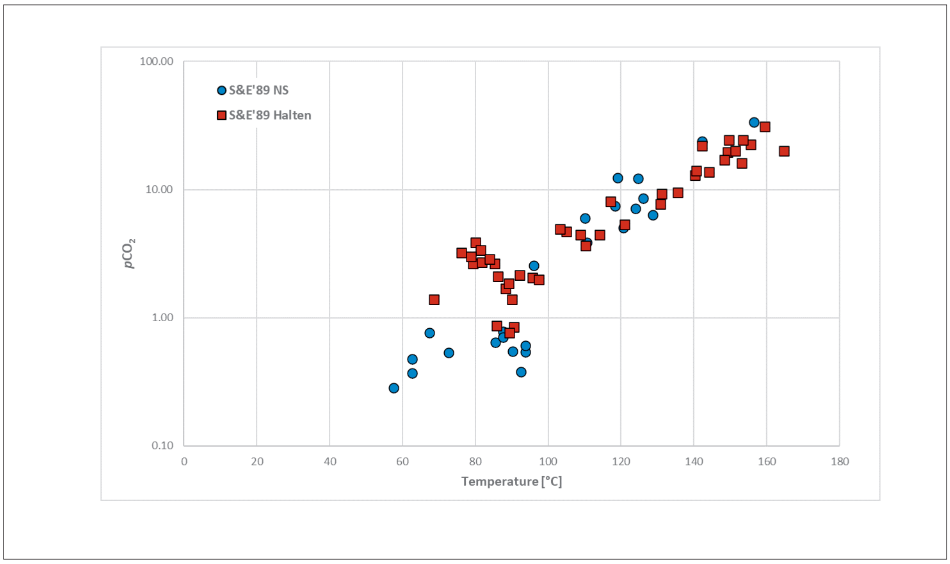
APT introduces CO2 database for North Sea CCS

Applied Petroleum Technology (APT) has compiled a large pressure-temperature-CO2 database for the North Sea to support operators that consider offshore storage of CO2.

The storage of CO2 in the subsurface has been proposed as a means to reduce CO2 release into the atmosphere, but this will require an understanding of the rock-fluid interactions.

The introduction of CO2 into a reservoir system can lead to the dissolution of certain minerals that will alter the intrinsic physical and geomechanical properties of both the reservoir and seal, which in term can potentially reduce seal capacity (e.g. Kim & Santamarina, 2014).

Alternatively, the introduction of CO2 in a reservoir can lead to mineral precipitation – securely sequestering the carbon. Whether mineral dissolution or precipitation occurs will depend on the reservoir pressure and temperature, mineral and formation water composition.



pCO2 versus temperature for petroleum reservoirs from the Norwegian North Sea and Haltenbanken basins

CO2 has three principal sources in the subsurface: from organic carbon buried in the sediment, from carbon stored within principally carbonate minerals and from the deep Earth. Upon burial sedimentary organic matter is converted first to a complex macromolecule ('kerogen') during early diagenesis, which itself is then modified with progressive burial, undergoing thermal decarboxylation between ~50-100°C producing CO2.

Carbonate minerals may form CO2 via dissociation due to chemical buffering with silicates (typically >70°C). Finally, CO2 may originate from deep-seated sources from either the thermal breakdown of carbonates or from volcanic sources. The latter source leads to the highest concentrations in sedimentary basins and can have important consequences for petroleum exploration in such basins, however such areas, with already high CO2 levels in the subsurface may be avoided as potential sites for carbon capture and storage (CCS).

With respect to CO2 storage understanding the inorganic reactions between carbonates and silicates is of most importance, since potentially significant changes in physical properties of the rocks may occur as a result (Noiriel & Daval, 2017).

It is known that the CO2 concentration is controlled by buffering by feldspar, clay and carbonate minerals. CO2 and hydrogen ions (acidity) reach a temperature mediated equilibrium which is strongly dependent on the mineralogical composition.

While the mineralogical make-up is typically either unknown or uncertain, plots of temperature vs the partial pressure of the CO2 (pCO2) exhibit clear trends in disparate clastic and volcanic basins, as shown in Figure 1 (cf. Smith & Ehrenberg, 1989; Hutcheon & Abercrombie, 1990).

This indicates that all the potential reactions between feldspar, clay and carbonate minerals result in an equilibrium relationship between the partial pressure of the CO2 (mol% CO2 * fluid pressure, as an estimate of the fugacity) and temperature.

However, assessment of data can also play an important role in understanding what fluid-rock interactions are taking place. To that end, we have compiled a large pressure-temperature-CO2 database for the North Sea.

The relationship between temperature and pCO2 is present but additional complexity is clearly also present and may indicate additional processes such as biodegradation or the recent addition of CO2 to the reservoir from a deep source (that has had time to equilibrate), furthermore we have observed some distinct local trends which may relate aH+ (where Formation waters are saturated with CO2). We're currently exploring what further insights can be drawn.

The database currently includes 954 pressure-temperature-CO2 mol % data points. This forms part of the APvT database.

More information

www.apt-int.com/services/apvt


Sulzer - lowering carbon emissions with cost-effective investments