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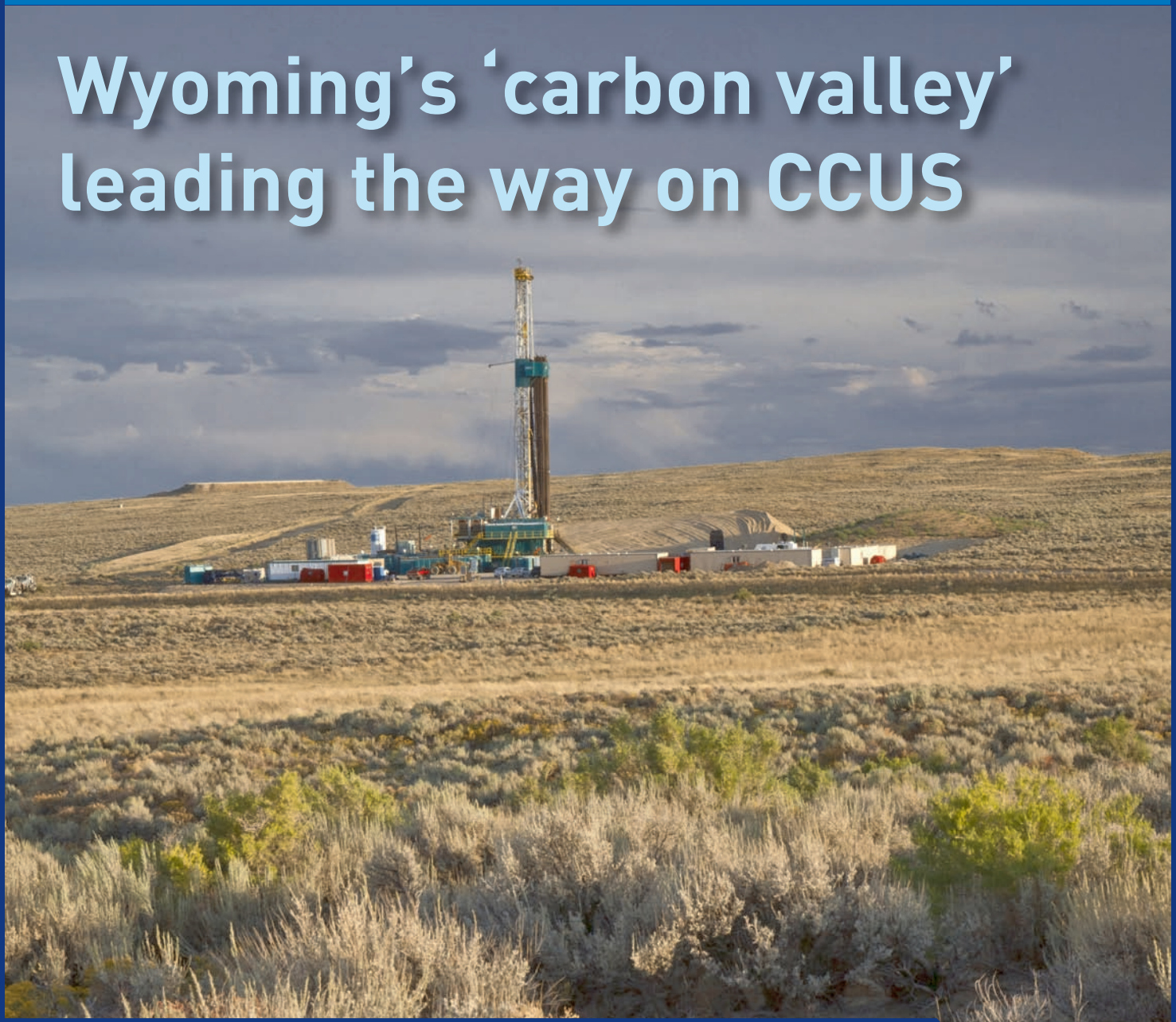

Carbon capture in India – our report from a high level webinar

Clean electrification and hydrogen can deliver net-zero by 2050

Carbfix builds a CO2 Mineral Storage Terminal in Iceland

Wärtsilä highlights potential for marine CO2 scrubbers and CO2 shipping

XPRIZE announces winners

CarbonCure Technologies and CarbonBuilt have won the $20M NRG COSIA Carbon XPRIZE, a prize that set out to convert CO2 emissions into valuable products.

Selected by a panel of independent judges, both winning teams developed solutions aimed at reducing CO2 emissions associated with traditional concrete, which is currently the world's most abundant human-made material and accounts for seven percent of all global CO2 emissions. The two team's award-winning technologies will be, and already are, game-changers for global decarbonization and the fight against climate change.

Launched in 2015, the NRG COSIA Carbon XPRIZE was a five-year global competition developed to address rising CO2 emissions by challenging innovators around the world to develop breakthrough technologies that convert the most CO2 into products with the highest net value.

The competition included two tracks, the Wyoming track that focused on the conversion of emissions from a nearby coal-fired power plant, the Wyoming Integrated Test Center in Gillette, WY, and the Alberta track which used emissions from an adjacent natural gas-fired plant, the Alberta Carbon Conversion Technology Centre in Calgary, AB.

The winning teams, one from each track, converted the most CO2 into products with the highest value, while minimizing their overall CO2 footprint, land use, water use, and energy use.

CarbonCure Technologies, the Alberta track winner from Canada, demonstrated a technology which enabled the production of concrete with a reduced water and carbon footprint without sacrifice to the material's reliability. Utilizing CarbonCure Technologies' system, a precise dosage of CO2 is injected into a concrete plant's reclaimer system, which contains the water used to wash out concrete trucks and mixers.

The CO2 is converted to a permanently embedded mineral with strength-enhancing properties which can then be incorporated into new concrete mixes. By reducing the amount of new freshwater, solid waste disposal and cement required, the team, which is backed by Bill Gates' fund Breakthrough Energy Ventures, Amazon Climate Pledge Fund, BDC Capital and others, is able to reduce the material costs and increase profitability for concrete producers.

"I'm incredibly proud of Team CarbonCure's hard work, dedication, and ingenuity that contributed to our win. The prize winnings will accelerate our path to achieve our company mission of reducing 500 megatonnes of CO2 emissions annually by 2030," said Jennifer Wagner, president of CarbonCure and team lead for the competition.

"Technology alone will not get us to our net-zero emissions targets — concrete producers, the wider construction community, and policymakers are important allies on our journey to decarbonize the concrete industry."

The Los Angeles-based Wyoming track winner, UCLA CarbonBuilt, developed technology that reduces the carbon footprint of concrete by more than 50 percent while reducing raw material costs and increasing profitability. The CarbonBuilt concrete formulation significantly decreases the need for ordinary Portland cement while enabling the increased use of low-cost waste materials.

During the curing process, CO2 is directly injected from flue gas streams (like power plants or cement factories) into the concrete mixture where it is chemically transformed and permanently stored. Development began at the UCLA Samueli School of Engineering in 2014 with support from the NRG COSIA CARBON XPRIZE, philanthropic foundations, private and corporate sponsors, as well as government agencies including the U.S. Department of Energy.

"I am absolutely thrilled that UCLA CarbonBuilt has won the NRG COSIA Carbon XPRIZE," said Gaurav N. Sant, professor of civil and environmental engineering and of materials science and engineering at UCLA Samueli.

"As a third-generation civil engineer, I have been fascinated with the role that construction has played in solving societal challenges. To have spent the last decade finding a solution to mitigate the carbon footprint of concrete construction with a phenomenal team, and to have won the NRG COSIA Carbon XPRIZE doing so is an ultimate dream come true," shared Sant, who is also the director of the UCLA Institute for Carbon Management and founder of CarbonBuilt, Inc., a private company set up to commercialize the pioneering CO2 utilization technology.

Additional X-Factor awards were given to Carbon Upcycling-NLT and Carbon Corp, two finalists that created excellent products and compelling demonstrations that deserved recognition.

Carbon Upcycling-NLT, based in Calgary, produces nanoparticles with applications in various industries, particularly concrete, construction and plastics.

Carbon Corp, who relocated from the USA to Calgary, transforms CO2 into carbon nanotubes, with applications such as lightweight, ultra-strong and cost-effective replacements for metals; stronger cement-composite building materials; and expanding applications in industrial catalysis, batteries, and nanoelectronics.

"Combating climate change is one of the most important challenges we face--requiring us to rethink, reimagine, and embrace new ideas," said Jeanne-Mey Sun, NRG vice president, sustainability.

"Competitions, such as the NRG COSIA Carbon XPRIZE, are opportunities to bring innovators together to develop solutions for the monumental task of decarbonizing our economy. As we recognize today's winners, we celebrate all of the teams' hard work and perseverance in this new era in carbon technology."

Each grand prize winner will be awarded a USD $7.5 million prize purse, and will receive their winnings within 60 days.

More information

www.xprize.org

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Front cover:

Drilling a test well at the CarbonSAFE project proving CO2 storage will be ready for commercial operation (pg. 11)

Back cover: XPRIZE winners: Gaurav Sant, a professor of civil and environmental engineering at the UCLA Samueli School of Engineering, holding samples of the concrete produced using the technology his team devised (UCLA Samueli School of Engineering)

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Leaders - CCUS in Europe

Projects and policy

Capture and utilisation

Transport and storage

ALIGN-CCUS findings: deep decarbonisation within reach

The result of over three years research, the international ALIGN-CCUS partnership has unveiled guidelines for accelerating the transition to a low-carbon economy for Europe's industrial regions.

An international partnership of science and industry has concluded three years of multi-disciplinary research aimed at transforming Europe's industrial regions into economically robust, low-carbon centres by 2025.

The ALIGN-CCUS project, funded through the ERA-NET ACT programme, focused on delivering tools and guidelines to support the quick and cost-effective delivery of large-scale CCUS technologies in Germany, the Netherlands, Norway, Romania and the UK.

The ALIGN-CCUS project's key results include:

• Rigorous pilot-scale testing of carbon dioxide capture technology over a record number of hours to address technical challenges

• New standards and solutions for cost-effective, reliable CO2 transport and injection

• A new standard for characterising geological CO2 storage sites during CCUS development

• Ambitious large-scale demonstration of synthetic fuel production from CO2 in an industrial setting

• Practical guidelines for developing full-chain CCUS for industrial clusters

• The most extensive international research on societal perceptions and impact of CCUS

The ALIGN-CCUS project saw 30 science and industry partners from five European nations collaborate on climate action. Researchers shared their findings online late last year during two half-day sessions attended by a wide range of international stakeholders, from potential CCUS operators to policy makers and NGOs.

Ragnhild Rønneberg, Research Council of Norway and ERA-NET ACT Programme Coordinator, said, "International R&D collaboration and knowledge sharing are key elements in the successful development and implementation of CCUS. ALIGN-CCUS has really shown that joining forces, resources, skills and tools across borders provides results that the CCUS community itself can be proud of but which also have great implications for society and policy development for CCUS in Europe."

Project overview

ALIGN-CCUS covers the whole Carbon, Capture, Utilisation and Storage (CCUS). It was one of the first projects where capture, transport, storage, utilisation, clusters and public perception interact to deliver the overall project objective: to accelerate the transition of current industry and power sectors into a future of continued economic activity and low-carbon emissions, in which CCUS plays an essential role.

ALIGN-CCUS addressed specific issues across the CCUS chain for industrial regions in ERA-NET ACT countries, enabling large scale, cost effective implementation of CCUS by 2025. All the chain elements contributed to this overall objective.

Dissemination was an important part of ALIGN-CCUS. Dissemination of project results was actively pursued, considering the interest of the project partners, with TNO and experts from the Scottish Carbon Capture & Storage (SCCS) teaming up in delivering the dissemination activities.

The ALIGNwiki site – https://wiki.alignccus.eu/ – developed by TNO, was launched in March 2020, providing user-friendly access to project objectives and outputs for a non-expert audience. The Wiki helped to deliver one of the key objectives of project C&D, that is, to disseminate findings and explain CCUS in engaging ways that allow the public to understand and assess their broader significance.

Summary of research

WP1: Enable near-term deployment of integrated capture facilities and cluster development

Solvent emissions: technologies for emission control were reviewed, tested at lab and pilot scales, and evaluated from both technical and economic perspectives. The main message is that emission control is technically feasible (for mitigating both aerosol and volatile emissions) and does not lead to prohibitive costs.

Solvent management: degradation of the solvent and corrosivity are decisive factors for the CO2 capture costs. The right choice of degradation countermeasures allows the operator of the capture plant to minimize solvent consumption and operational issues like foaming and fouling, downtimes for maintenance and waste streams and offers the supplier the chance to use cost effective materials for the design of the capture plant.

Process dynamics and control: due to the penetration of renewable intermittent energy in most energy systems, natural gas and coal power plants must be operated in a flexible mode to stabilize the electrical grid.

Benchmarking and cost drivers: one of the aims of the ALIGN-CCUS project is to evaluate if the second generation solvent CESAR1 can be established as the new state-of-

the art benchmark solvent system, replacing monoethanolamine (MEA), and propose an optimal CO2 capture process implementation and integration with power plants and other industrial sources.

WP2: Removing technical barriers to large-scale CO2 transport

The three overall objectives of WP2 were:

• Develop optimum handling strategies of both low- and medium-pressure CO2 on vessels in a transportation network, and in offshore offloading systems including required equipment types.

• Investigate use of different solutions including Floating Production, Storage and Offloading units (FPSOs) and/or subsea solutions and identify new chain configurations.

• Suggest optimum combinations between transport solutions and offshore offloading solutions, and establish a benchmark for alternative transport strategies, including cost considerations.

WP2 has demonstrated that low pressure ship transport of CO2 may be just as (or even more) attractive than the medium pressure transport option, which is the proven technology today. Cost-wise these two options are quite similar. The cheapest injection option seems to be direct injection from a ship.

WP3: Large-scale storage networks

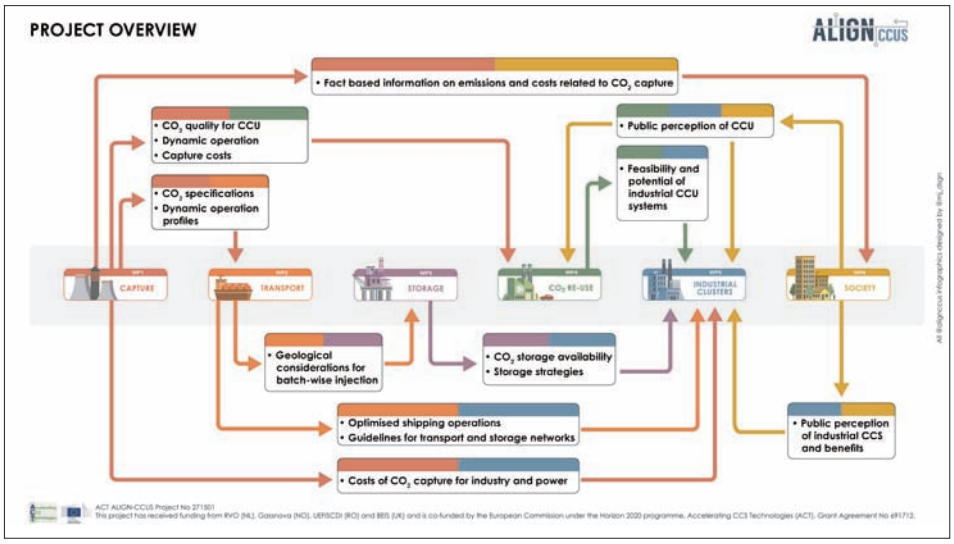
WP3 objectives were to investigate:

• A methodology to produce standardised definitions of the levels of storage readiness for putative storage sites across the North Sea and corresponding activities for them to become a contingent storage resource.

• A portfolio of selected storage sites that have been characterised to provide strategic storage for the leading ALIGN-CCUS industrial clusters most likely to form the backbone of CCUS in north-west Europe.

• An audit of North Sea transport and injection infrastructure that provides least-cost options for storage network development.

All WP3 deliverables and objectives were successfully achieved incorporating additional linkages and exchanges between the tasks, with WP5, parallel investigations for industry and the ACT ELEGANCY and Acorn projects.



Overview of the ALIGN-CCUS project

WP4: CCUS as an element for large-scale energy storage and conversion

For the first time a full CCU chain for the production of the eFuel dimethyl ether (DME) from captured CO2 and electrolytically produced H2 was demonstrated in ALIGN-CCUS.

In addition to the development, construction and operation of the Power-to-DME plant, the demonstration comprised also the successful use of DME as a fuel for peak and back-up power generation and of OME (polyoxymethylene dimethyl ethers, which can be produced from DME) as a fuel for passenger cars. Both objectives, to present the potential of CCU regarding climate protection and to demonstrate its benefit and socio-economic value as an element for large-scale energy storage and sector coupling, were achieved.

Two patent applications on the technical and economic optimisation of the DME synthesis process and efficiency enhancement due to optimised integration of a DME-fuelled peak-power generation into power plant processes have been applied for.

WP5: Targeted CCUS activities in industrial clusters

The work in WP5 has advanced the development of CCUS in six industrial regions across five European countries. The work will support national and regional governments in future decision-making for industrial decarbonisation strategies within the targeted regions but has also draw together synergies from each case studies to help a more generic approach to cluster developments in Europe.

Greater clarity can now be provided on the expected investment requirements and benefits for public and private actors of hub and cluster developments for CCUS.

WP6: Implementing CCUS in Society

The overall objectives of WP6 involved the reduction of non-technical risk for CCUS implementation by:

• Assessing public and stakeholder perception about CCUS, specifically towards industrial CCUS and CO2 utilisation projects (Tasks 6.1 and 6.3);

• Developing theory-based, evidence-based communication and compensation strategies that instigate trust and have a positive effect on societal acceptance of CCUS

More information

The full results are available at:

www.alignccus.eu

DTU leads large EU project to develop electricity-based CCS

Partners from Denmark, the Netherlands, the UK, Romania, Greece, China and Canada have joined forces to enable electrochemical reduction of carbon emissions in a new Horizon 2020 project.

ConsenCUS is a four-year international innovation project under the EU's Horizon 2020 framework programme.

The project explores how electrochemically driven carbon capture and conversion innovations can be combined with safe transport and/or storage through economically viable networks and clusters, with particular focus on interactions between local communities and technological developments.

DTU will coordinate the construction of mobile demonstration facilities to be tested at three different locations in the EU: the cement factory Aalborg Portland, the Greek mining company Grecian Magnesite and the Romanian refinery OMV Petron. A common feature of all three companies is that their production inevitably results in high levels of carbon emissions. The demonstration facilities are expected to collect around 100 kilos of CO2 per hour, which will then be converted into usable chemicals.

So far, carbon capture, use and storage only takes place in a few places around the world, often using fossil fuels to run the boilers that regenerate the carbon-absorbing material. The new consortium, called ConsenCUS, wants to enable CCUS using renewable energy sources to make it more sustainable and even climate neutral.

"We need to put a plug in the chimneys. The CO2 must be captured, and there's no getting around it: we need power, and it must come from renewable energy sources. Chemistry in the 21st century will be based on electricity, so of course carbon use and storage should be too," says Philip Loldrup Fosbøl, Associate Professor at AT-CERE at DTU Chemical Engineering.

"At Aalborg Portland, we're very excited to be part of this strong international consortium, where we'll work closely with DTU to test brand-new and efficient carbon capture technology at our cement factory. This can open up for new opportunities to create much better financial conditions for carbon capture," says Michael Lundgaard Thomsen, CEO of Aalborg Portland, and continues:

Associate Professor Philip Loldrup Fosbøl and Senior Project Manager Sebastian Nis Bay Villadsen standing on a container-based pilot unit (Photo: Christian Warm)

"The project will also explore possible synergies in cluster and value chain collaborations, which we consider essential if we're to succeed with CCUS on a large scale in North Jutland, because it will require the involvement of several players."

How it works

In practice, the carbon will be captured by using an alkaline liquid to bind it. At low temperatures, the carbon is released electrochemically and collected. The liquid can be reused to capture more carbon.

The collected carbon will be used to produce formic acid, which has a number of applications in the chemical industry – for example as a hydrogen source in the transport sector and as a building block in the plastics industry. The use of formic acid is expected to increase in the future.

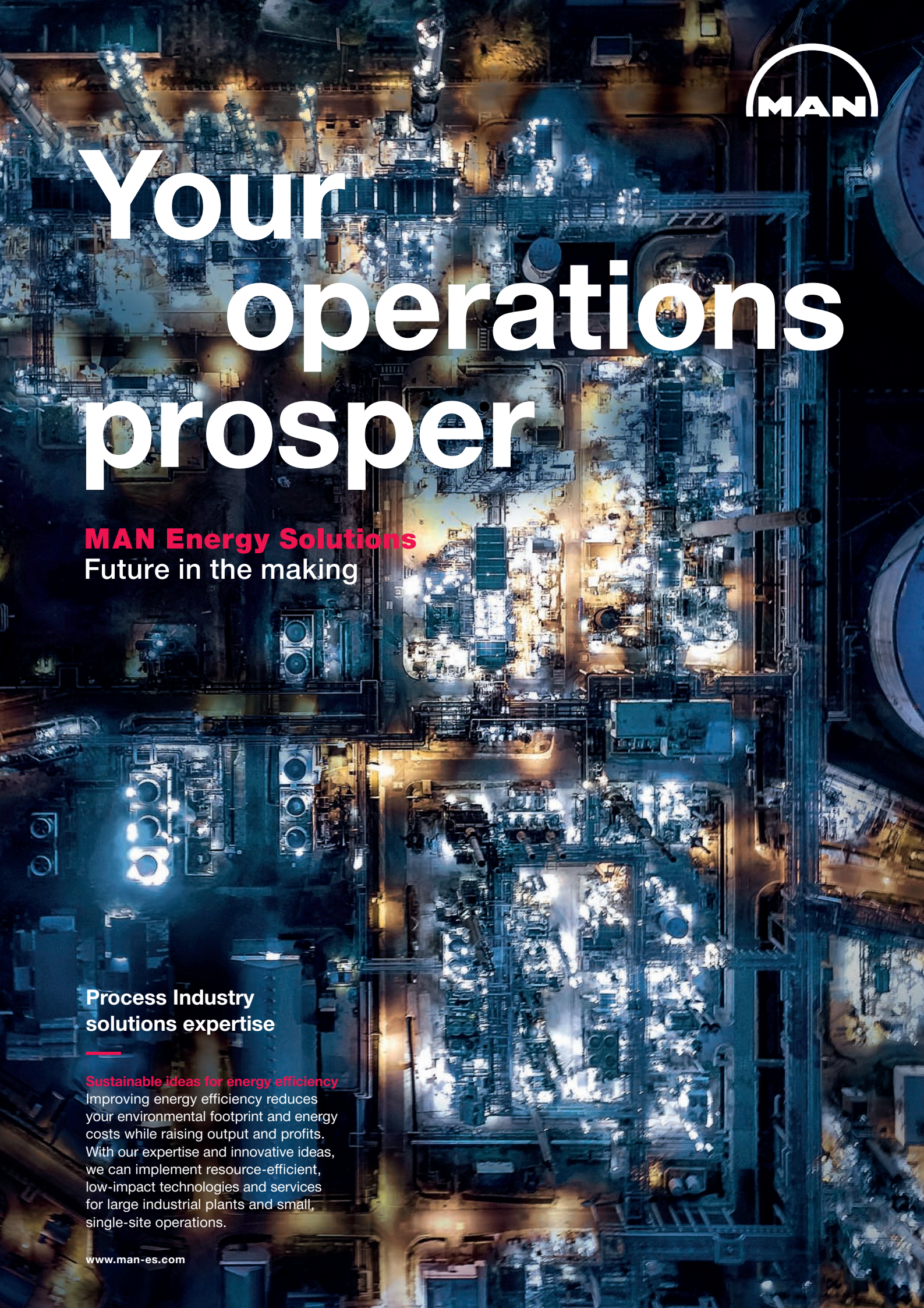
"At the Danish Gas Technology Centre, we already work with carbon and hydrogen. So it's very gratifying to have the opportunity to support such a large project with our knowledge in the field. In this way, we can contribute to a greener and more flexible energy system, where safety remains a high priority," says CEO Thea Larsen.

At the same time, the researchers will examine the opportunities and challenges that the carbon technologies will bring to the local economy, geology and society. The aim is for regional companies to work with governments and citizens to make smart investments in shared infrastructure, such as pipelines or temporary storage sites.

"We see the use of electricity in carbon technologies as a big part of the future. A future where we hope that Denmark will play a big role, both in terms of workplaces and research," says postdoc Sebastian Nis Bay Villadsen from AT-CERE at DTU Chemical Engineering.

More information

www.dtu.dk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Establishing CO2 enhanced oil recovery in South Eastern Europe

The ECO-BASE project, part of the EU ACT initiative, aims to develop revenue streams and business models for CO2-EOR in South-Eastern Europe therefore supporting large scale CCUS deployment.

The objective of the ECO-BASE project was to investigate the potential of commercially deploying CCUS by screening available data, developing CCUS roadmaps and exploring for potential CO2 Enhanced Oil Recovery (CO2-EOR) pilots in South-East Europe. ECO-BASE has assessed the potential for CO2-EOR through the following activities:

• Creating an inventory of CO2 sources (potential capture projects) and sinks (potential sites for CO2 usage through CO2-EOR) in Romania and Turkey;

• Identifying possible source/sink clusters and performing case studies to evaluate the business potential of combining CO2-EOR and permanent CO2-storage;

• Setting up regional CCUS development plans through CO2-EOR roadmaps;

• Organizing knowledge transfer workshops for local CCUS stakeholders.

Through selected case studies in Romania and Turkey, the ECO-BASE project provided insight into prospective revenue streams and business models for CO2-EOR in SE-Europe, with a long-term view to large-scale CCUS regional deployment. The project was financed in part by the EU ACT programme, and carried out by organizations in Turkey, Romania, the Netherlands, and Norway.

The case studies focused on the technical and business aspects of CO2 emitters and oil field operators, potentially in demand for CO2, to analyse the full value chain, but also included executing an environmental impact study and the assessment and development of the public perception over the duration of the ECO-BASE project.

A prerequisite for realizing a CCUS/CO2-EOR chain, i.e. with the CO2 captured from industrial plants, is that all actors along the value chain have a positive business case. This includes the emitter capturing CO2, the CO2 transport operator that operates the pipeline, ship, or trucking facilities, and the operator of the oil reservoir where the CO2 is utilized and stored.

The business cases are typically assessed by defining a series of key performance indicators, with quantitative estimates of how the activity, as defined by a series of alternative decision pathways, may lead to positive future discounted cumulative net cash flows (NPV), including the associated uncertainties.

The basic premise of a rational investment decision process is that the internal rate of return must exceed each company's weighted cost of capital, plus a risk and a profit margin. Business risks were identified and quantified, with due regard to the 'first of a kind' infrastructure nature and commercial complexity of these projects.

Conclusions

The main merit of the ECO-BASE project is that for the first time a methodology was developed and applied to actual case studies, despite the limited accessibility to field-specific data. This enabled the ECO-BASE team of researchers to assess the economic feasibility of CO2 capture from industrial plants in Romania and Turkey, with CO2 capture and transport to nearby producing oil fields.

At the oil fields the CO2 is injected both for Enhanced Oil Recovery purposes and for permanent sequestration of the CO2 (the so called 'EORStore' concept). The methodology developed and presented to stakeholders in Romania and Turkey (i.e. government and industries) was aimed at initiating a discussion on possible next steps to further mature the concept of EORStore in Romania and Turkey.

Although actual available field data were limited, or even inaccessible due to their confidential nature, it can be argued that, potentially, significant amounts (up to tens of million tons) of CO2 can be permanently stored in the oil reservoirs, and that this can be achieved under economically profitable conditions. This is because only a fraction of the injected CO2 is back-produced, and then separated, compressed and re-injected.

In the end, all the CO2 transported to the field ends up in the ground, and significant value is generated to all stakeholders in the CCUS-chain by the incremental oil sales and, in case of Romania, the avoidance of having to purchase emission rights by the coal-fired power plant. Investments risks are manageable and seem commensurate with the reward, as given by the IRR decision metric. Stakeholders are encouraged to further investigate these possible business advantages and mature the concept to a next stage.

These 'first-of-a-kind' projects also address the role of the government to stimulate the development of an initial CO2 infrastructure by providing guarantees and, if necessary, also subsidies. Follow-on projects in the designated potential regional CCS clusters, West-Oltenia in Romania and Batı Raman in SE Turkey, could profit from this initial infrastructure and would incur less risk.

Although one could argue that incremental oil production is inconsistent with CCS, as the incremental oil will lead to incremental CO2 emissions, the rationale is that EOR-Store provides a means to finance the initial, first-of-a-kind CO2 infrastructure, which otherwise would not have been realised.

It can be concluded that, in South Eastern Europe, CO2-EOR has the potential to justify economically first-of-a-kind CO2 infrastructure and sequestration projects that would not have been feasible without the CO2 usage by producing oil fields.

More information

ecobase-project.eu

New catalyst developed at TU Wien for lower CO2 emissions

Scientists at TU Wien have succeeded in producing a special perovskite that is excellently suited as a catalyst for converting CO2 into other useful substances, such as synthetic fuels.

At TU Wien, research is being conducted on a special class of minerals - the perovskites, which have so far been used for solar cells, as anode materials or electronic components rather than for their catalytic properties.

"We are interested in the so-called reverse water-gas shift reaction," says Prof. Christoph Rameshan from the Institute of Materials Chemistry at TU Wien. "In this process, carbon dioxide and hydrogen are converted into water and carbon monoxide. You can then process the carbon monoxide further, for example into methanol, other chemical base materials or even into fuel."

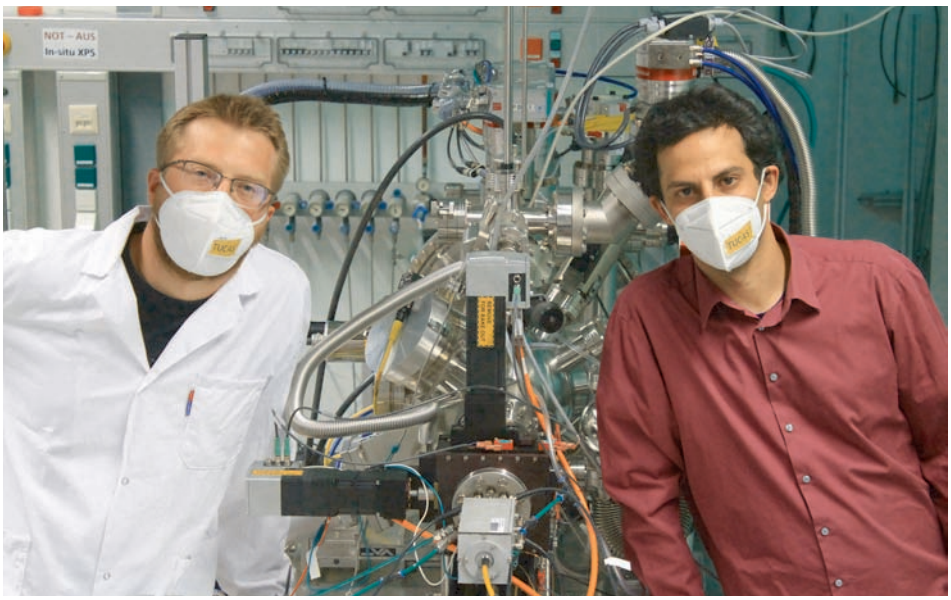
This reaction is not new, but it has not really been implemented on an industrial scale for CO2 utilisation. It takes place at high temperatures, which contributes to the fact that catalysts quickly break down. This is a particular problem when it comes to expensive materials, such as those containing rare metals.

Christoph Rameshan and his team investigated how to tailor a material from the class of perovskites specifically for this reaction, and he was successful: "We tried out a few things and finally came up with a perovskite made of cobalt, iron, calcium and neodymium that has excellent properties," says Rameshan.

Atoms migrating through the crystal

Because of its crystal structure, the perovskite allows certain atoms to migrate through it. For example, during catalysis, cobalt atoms from the inside of the material travel towars the surface and form tiny nanoparticles there, which are then particularly chemically active.

At the same time, so-called oxygen vacancies form - positions in the crystal where an oxygen atom should actually sit. It is precisely at these vacant positions that CO2 molecules can dock particularly well, in order to then be dissociated into oxygen and carbon monoxide.



Lorenz Lindenthal (left) and Christoph Rameshan (right) have developed the catalyst that helps to convert CO2 to other chemicals

"We were able to show that our perovskite is significantly more stable than other catalysts," says Christoph Rameshan. "It also has the advantage that it can be regenerated: If its catalytic activity does wane after a certain time, you can simply restore it to its original state with the help of oxygen and continue to use it."

Initial assessments show that the catalyst is also economically promising. "It is more expensive than other catalysts, but only by about a factor of three, and it is much more durable," says Rameshan. "We would now like to try to replace the neodymium with something else, which could reduce the cost even further."

The industrial plant with built-in fuel production

Theoretically, you could use such technologies to get CO2 out of the atmosphere - but to do that you would first have to concentrate the carbon dioxide, and that requires a considerable amount of energy. It is therefore more efficient to first convert CO2 where it is produced in large quantities, such as in industrial plants.

"You could simply add an additional reactor to existing plants that currently emit a lot of CO2, in which the CO2 is first converted into CO and then processed further," says Christoph Rameshan. Instead of harming the climate, such an industrial plant would then generate additional benefits.

The research was published in a paper: L. Lindenthal et al., Novel perovskite catalysts for CO2 utilization - Exsolution enhanced reverse water-gas shift activity, Applied Catalysis B: Environmental, 292, 120183 (2021).

More information

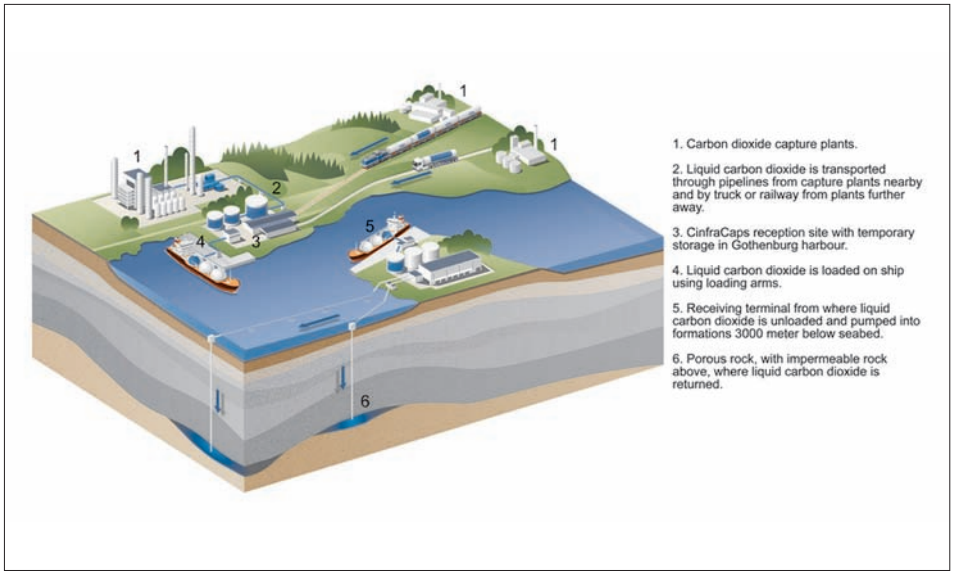
www.tuwien.at

Gothenburg region sees potential for significant gains from CCS

The Gothenburg CinfraCap project is now complete and has concluded CCS offers a cost-effective path to meet climate goals through shared infrastructure.

Working in partnership, companies in the Gothenburg region can achieve their climate goals more rapidly although it will require an investment running into billions. This is the conclusion reached following a prestudy of a joint infrastructure for the transport of captured and separated carbon dioxide that has just been presented by CinfraCap.

CinfraCap is a unique collaborative project between Göteborg Energi, Nordion Energi, Preem, St1, Renova, and the Gothenburg Port Authority. The project is focused on the cost-effective, climate-smart transport of captured carbon dioxide from each company down to the port. The prestudy, conducted with the aid of the consulting group COWI, presents the potential for developing a joint logistics and infrastructure solution.



Prestudy of the Gothenburg CinfraCap project is now completed and sent to the Swedish Energy Agency

It includes proposals for optimising carbon capture and interim storage prior to loading, identifying inherent risks, and securing the necessary permits. Also included are proposals for a business model, which could be extremely useful in similar projects at other locations throughout Sweden.

The project has the potential to store around two million tonnes of carbon dioxide each year from the participating companies alone. This is equivalent to 75 per cent of the total emissions from domestic transport in the Västra Götaland region. The plan is for the infrastructure to operate on an open-access basis via third-party affiliation, offering further potential for an increase in the volume of carbon dioxide handled each year.

"This is a unique solution that Gothenburg and Sweden could be the first in the world to introduce," said project leader Karin Lundqvist from Preem.

"There are significant gains to be had from working together to create a CSS (Carbon Capture and Storage) infrastructure in western Sweden. Having said that, it is an extremely costly project to implement and will require support and funding from various government agencies and authorities, backed by financial incentives to ensure a willingness to invest."

The final report will be sent to the Swedish Energy Agency, which through its climate initiative Industrial Evolution (Industriklivet) has funded half the cost of the project. The report will be available to anyone who is interested.

The parties involved intend to continue discussing ways to bring this initiative to fruition, focusing not only on the technical aspects but also on the commercial prerequisites and the necessary rules and regulations surrounding CCS/Bio-CCS.

CinfraCap stands for Carbon Infrastructure Capture. The project is focused on the transport of captured carbon and how this can be done in a climate-smart, cost-effective way.

The aim behind CinfraCap is to produce a more comprehensive picture of the logistics chain required to transport captured carbon dioxide from different industrial facilities in western Sweden – from liquefication and intermediate storage, through to distribution to ships and onward transport to the repository site. The interface for CinfraCap will be the fence around the facility in western Sweden that captures the carbon dioxide, through to the loading arm on the vessels that transport the liquefied carbon dioxide onwards by sea.

CinfraCap will complement a number of other ongoing research and development projects, including Preem CCS, ZEROC, and Northern Lights, which is a full-scale carbon dioxide repository project being run off the west coast of Norway. CinfraCap is a collaborative venture between Nordion Energi, Göteborg Energi, Renova, Gothenburg Port Authority, Preem, and St1.

More information

www.portofgothenburg.com

CO2 storage must be recognised in the revised TEN-E Regulation

As part of the ongoing revision of the guidelines for Trans-European Energy Infrastructure (TEN-E) Regulation, Bellona Europa has together with Clean Air Task Force (CATF) put together a campaign to raise important points and issues on the current proposal from the European Commission.

The first interview from the series was with ARC CEO Jacob Hartvig Simonsen

While perhaps best known for the innovative use of its roof as a ski slope in central Copenhagen, ARC is one of the world's cleanest and most energy efficient waste to energy plants. And they're aiming even higher, planning to capture and store 500,000 tons of CO2 annually by 2025. ARC CEO Jacob Hartvig Simonsen joined Bellona to weigh in on the importance of recognizing CO2 storage and transport modalities other than pipelines in the Revised TEN-E Regulation.

Why is ARC so interested in CO2 Capture and Storage?

First of all, the amount of carbon dioxide in the atmosphere is way too high. This is the core of the climate crisis – and we must find ways to lower it. When capturing CO2 and storing it underground we effectively reduce emissions, and when it comes to biogenic CO2 we actually remove CO2 from the atmosphere!

Of course, carbon capture and storage cannot stand alone as a climate measure for dealing with or mitigating the climate crisis – a multifaceted approach is needed. But, as we believe at ARC, we will not be able to meet the goals of the Paris Agreement without CO2 Capture and Storage.

ARC is one of the world's cleanest and most energy efficient waste to energy plants, in place since 2017, and now we want to take it to the next level by introducing carbon capture and storage. While the complete value chain of our project consist of 3 parts: capture, transport and storage, one of the main risks for our project is the storage of our captured CO2.

ARC's CCS project 2025

ARC's CCS project will aim to put up a full-scale carbon capture plant by 2025. This full-scale plant will have the capacity to capture 95% of the flue gas - for ARC this amounts to removing 500,000 tonnes of CO2 annually. This will significantly support Copenhagen to achieve its ambition of being the world's first CO2-neutral capital in 2025.

While carbon capture is normally a very energy intensive process, the project at ARC aims to show that carbon capture can be achieved with neutral energy consumption - this is possible as residual heat from the capture process can be re-harvested and turned into district heating.

ARC's efforts and technological developments will also be applicable for other waste to energy facilities across Europe, as long as they are connected to district heating networks. This and similar future projects' ability to realise such ambitious plans for decarbonisation depends on the right regulatory framework, sufficient funding and a mature market for transporting and storing CO2.

What role can the revision of the TEN-E Regulation play?

It can help address what we at ARC call the "Carbon Capture and Storage Paradox". On the one hand large emitters can start capturing CO2, but can't be certain that the captured CO2 can be stored at a competitive price. On the other hand, large corporations need to invest huge amounts to develop storage sites but can't be certain that there will be enough customers.

In this sense, the current CO2 storage market is not mature – and the high prices associated with storage could get in the way of deploying large-scale CO2 capture. When revising the TEN-E, it is vital to both include carbon dioxide transport and storage. And in fact, the European Green Deal states that the TEN-E regulation should foster the deployment of innovative technology and infrastructure such as carbon capture and storage.

In our view, recognition of the full value chain in the TEN-E would undoubtedly help spark the deployment of carbon capture and storage at a large scale across Europe. This is vital as it is a necessary means to dealing with the climate crisis

How can CO2 storage recognition in the TEN-E contribute to cross-border benefits in the EU?

Storage facilities are unevenly distributed across Europe. Meaning that as we need this technology at a large scale for Europe's decarbonisation efforts, Member States with no access to storage facilities must be able to access CO2 storage sites other places in Europe.

Putting up a pipeline to transport the CO2 is fine, but in the end if you do not have available storage as well, or too few with high prices, you will not reach the stage of transport – simply because the CO2 will not be captured to begin with.

Second interview, Mark Driessen from Porthos

Mark Driessen from Porthos had a chat with Bellona on the importance of recognizing CO2 storage and transport modalities other than pipelines in the revised TEN-E.

Why is Porthos so interested in carbon capture and storage?

It all initiated in the Port of Rotterdam, which most of you might already know is quite a big port. Following the Paris Agreement, the question arose: How can we decarbonise the industry in the port area? And: Is it possible to reach a 95% CO2 reduction in 2050?

Following research and analysis of all possible scenarios, our answer was clearly yes – but only if you include carbon capture and storage in the whole mix of technologies needed to decarbonise. This is where it started and why we are so interested! The only way to reach the set climate targets (In the Netherlands, 49% reduction in 2030) is through carbon capture and storage inclusion.

What role can the revised TEN-E regulation play?

The TEN-E Regulation has been essential for Porthos. Three years ago, we were awarded a project of common interest status, or PCI for short. That PCI status gave us access to all benefits included in the TEN-E Regulation. The two most important results for us were the speeding up of the project and access to funding.

Firstly, once you have the PCI status on the permitting side, the permitting process is quicker. Secondly, funding gave us access to the Connecting Europe Facility – known as the CEF. Funding is essential, and whichever way you look at it, a Carbon Capture and Storage project like this, at this stage, could not be realised without extra funding, which is why it was vital to us.

The revision of the TEN-E is a crucial opportunity to underline the importance of Carbon capture and storage as one of the pillars of the Green Deal. And it gives the possibility to strengthen the Regulation further and incentivise industries and other partners to start investing in what is needed to get Carbon Capture and Storage up and running – this includes the whole chain from capture to transfer to storage.

How can CO2 storage recognition in the TEN-E contribute to cross border benefits in the EU?

One thing that struck me when I looked into the TEN-E Regulation was storage. Storage was not included – this struck me as quite strange. Storage is the determining factor for your whole project! Let's be honest; the TEN-E Regulation has been very good for us because we have been awarded 102 million euros for our project. Which underlines the importance that the European Commission attaches to Carbon Capture and Storage, and we are very grateful for that because that was a real boost for the project. But if we want to develop further, then storage should be included.

Everyone should understand that developing a storage facility takes more time than building a capture facility or even the transport infrastructure. Developing a storage facility can run up to 6 years, and the inclusion of the TEN-E could speed up that process, especially around the storage permits.

From a European perspective, storage facilities are very unevenly distributed amongst the European Union Member States. The European Commission could make a real difference by recognising the transnational element and cross-border benefits of storage facilities and the importance of making CO2 storage available for countries who don't have these facilities in their own country. If we don't include that in the TEN-E, we risk member states developing storage fields only for their own use, leading to sub optimisation.

We could invest immediately in a more extensive storage facility with a more significant transport pipeline, making it cheaper for everyone to use. This would also assist in the Carbon Capture and Storage learning curve. From my perspective, that's probably the most important reason why storage should be included in the TEN-E Regulation now: to demonstrate and show that from a European perspective, these facilities should be open to all member states who want to make use of them.

The TEN-E revision doesn't include other transport modalities than pipeline. How do the other transport options than pipeline fit into the Porthos project?

At Porthos, we will start by transporting and storing two and a half million tonnes of CO2 per year. We are also building an on-shore system that could possibly accommodate up to 10 million tons in the future. But the interest shown in the Porthos project so far is way over 10 million tonnes. As such, this couldn't all be transported through our pipeline system in the port area.

Additionally, it's not always the best option to invest in a pipeline. Imagine you have a lot of CO2 together in a cluster, but the distance to Rotterdam is too far. In that case, a pipeline can't be an option. That's why we're working to see if we can connect three industrial clusters with the Port of Antwerp in Belgium and North Sea Port in the Netherlands. Other facilities – further away from Rotterdam with emissions perhaps not part of, or part of smaller, clusters – are already looking into CO2 transportation by ship and truck. They will be vital for the development of Porthos.

We are also trying to make it possible to bring CO2 by ship to Rotterdam for offload, and then finally transported to an offshore storage field. So that's also an important thing that should be included in TEN-E: other transport modalities in addition to pipelines. It's not always wise, efficient or possible to invest in pipelines.

The road to CO2 reduction through storage in the North Sea

The Porthos project aims to start transporting and storing two and a half million tonnes of CO2 per year starting in 2024 in the Port of Rotterdam. To make their final investment decision at the beginning of next year, they will need at least two years to build.

Porthos plans to store the CO2 in a P18 gas field beneath the North Sea (20 kilometres from the coastline of Rotterdam). These gas fields' capacity is estimated at 37 million tonnes, filling the gas field for around 15 years.

Porthos has also separated the transport and storage from the capture, meaning they are an independent open-access infrastructure for industrial clients. These clients are responsible for capturing and delivering the CO2.

More information

www.bellona.org
a-r-c.dk
www.porthosco2.nl

Wyoming's 'carbon valley' leading the way on emissions reduction

The nation's leading coal-producing state has set an ambitious goal of net-zero carbon emissions. To reach this goal, the state is leading several R&D efforts to harness/sequester CO2 emissions – including hosting the XPRIZE at the Integrated Test Center and projects from the University of Wyoming's School of Energy Resources.

Wyoming's Powder River Basin 'carbon valley' is leading efforts to turn CO2 emissions into useful products or store them permanently underground.

It is home to the Wyoming Integrated Test Center (ITC), a research test facility located on the site of Basin Electric Power Cooperative's Dry Fork Station (DFS) near Gillette, Wyoming where 5% of the plant's exhaust gas goes into a manifold system and can then be used to test CO2 capture technologies.

"Wyoming is the perfect place to conduct CCUS research," said Jason Begger, Managing Director of the ITC. "We have facilities, we have agencies with expertise in regulating CO2 and a 'get to yes' attitude towards permitting, we have a legislature and governor supportive of technology development and lastly, we have public support for these types of projects."

The ITC is one of only a handful of facilities around the world that enables researchers to test their technologies at an operating power plant. The ITC is able to host multiple research teams at any given time, accommodating projects of varying sizes and power needs. Kawasaki Heavy Industries will test their solid sorbent capture technology there.

The $20M NRG COSIA Carbon XPRIZE, a nonprofit initiative spurring tech innovation via competition, aims to convert CO2 emissions into usable commercial products. Finalists for the XPRIZE tested their technologies at the ITC. After five years the winners have now been announced and will split a $15M cash prize (see inside front cover).

"CO2 is a very simple molecule, consisting of one carbon and two oxygen atoms. The array of products that can be created from oxygen and carbon is almost limitless. Fuels, plastics, building materials and carbonates are all examples. The opportunities for managing or utilization of CO2 is expansive," said Mr Begger.

"CO2 management requires both the capture of CO2 and then permanently doing something with it to ensure it is not released into the atmosphere. The ITC is unique in that it has hosted both types of technologies.

Membrane Technology pilot

The ITC will host one of two projects selected by the U.S. Department of Energy (DOE) for Phase III funding of a large-scale pilot carbon capture project.

DOE announced it has awarded $99 million to two projects for Phase III funding. Membrane Technology and Research (MTR) was awarded $51,699,939 from DOE, and with additional non-federal funding, the project will bring over $64 million in research dollars into Wyoming.

"I am delighted that Membrane Technology and Research (MTR) has been selected to move forward in this process, and that Wyoming has been chosen to host this important demonstration of cutting edge carbon capture technology," said Wyoming Governor Mark Gordon. "This is exactly the type of research that was envisioned when the ITC was developed and Wyoming will continue to support these efforts."

"Membrane technology is a most promising version of carbon capture, and now it can move forward to the pilot project phase," the Governor added. "This is also an example of technology that, if commercially successful, can be exported for carbon capture projects at home or abroad. The more carbon capture technologies that are available, the more likely it is that Wyoming coal will be an important part of our future electricity supply."

CarbonSAFE

The DOE-funded Carbon Storage Assurance Facility Enterprise (CarbonSAFE) initiative was formed to provide a better understanding of integrated storage project screening; site selection; characterization; baseline monitoring, verification, and accounting procedures; and information necessary to submit permit applications.

The program was designed to build off of the lessons learned from the Regional Carbon Sequestration Partnerships to develop a path towards commercialization.

"Wyoming CarbonSAFE is leading the way for CO2 storage in Wyoming, the project is designed to work through the kinks of commercial storage projects and provide a path forward for others to follow," said Scott Quillinan, Director of Research School of Energy Resources, University of Wyoming.

"The Wyoming Energy Strategy calls for Wyoming natural resources to continue to power the nation and to have net-zero carbon emissions. Carbon capture use and storage is a key technology to get us there."

One of the compelling attributes of the project is the project location near the Dry Fork Station, one of the nation's newest and lowest emissions coal-fired power plants. DFS has over 50 years of remaining operating life.

The Powder River Basin is home to more than 40% of U.S. coal production and contains an estimated 1.16 trillion tons of coal resources. With respect to CO2-enhanced oil recovery, approximately 1.9 billion barrels of oil reserves remain in nearby oil fields. Lastly, the project is located near CO2 pipeline infrastructure.

The CarbonSAFE program is comprised of four phases. The Project team has previously

completed Phase I (Integrated CCS Pre-Feasibility) and Phase II (Storage Complex Feasibility) of the program. In Phase III, the project team will: (1) complete the characterization of the commercial-scale CO2 storage complex by rigorous commercial-scale surface and subsurface testing, data assessment, and modeling; (2) prepare and file Class VI permits to construct with the Wyoming Department of Environmental Qualify under the Underground Injection Control Program; (3) integrate MTR's separately funded CO2 capture study at DFS, and; (4) conduct required NEPA analyses in support of eventual commercialization of the site.

Phase I: Integrated CCS prefeasibility – an 18-month initiative consisting of the formation of a team, development of a feasibility plan, and high-level technical evaluation of the sub-basin and potential CO2 sources. Thirteen projects have been funded. This phase is complete.

Phase II: Storage Complex Feasibility – a 2-year initiative for data collection, geologic analysis, analysis of contractual and regulatory requirements, subsurface modeling, risk assessment, evaluation of monitoring requirements, and public outreach. Six projects have been funded.

Phase III: Site Characterization and CO2 Capture Assessment – a 3-year initiative to complete detailed site characterization and CO2 capture assessment, as well as obtaining National Environmental Policy Act approvals and underground injection Control (UIC) Class VI permits to begin construction.

Phase IV: Permitting and Construction of Storage Complex – a 2.5-year initiative focused on developing risk and mitigation plans, obtaining UIC Class VI permits to inject and completion of injection and monitoring wells.

Potential Project Impacts

By the completion of Phase III, the Project team will have finalized all site characterization and Class VI permitting activities, thereby leaving the Project poised to begin final commercialization actions (e.g., arranging financing, commercial operational designs) with the consent of Project partners.

In so doing, the Project will have commercially advanced CCUS technologies both technically (e.g., advancing the state of the science of reservoir characterization in the CO2 storage context) and nontechnically (e.g., obtaining the first Class VI permit to construct in the State of Wyoming). Beneficiaries of these advancements will include but are not limited to, DOE, the coal industry, and the utility industry.

The Project team expects four specific outcomes/impacts of high relevance to the advancement of CCUS: (1) reduce uncertainties and risk associated with surface and subsurface characterization; (2) obtain Class VI permits to construct; (3) integrate geologic storage and CO2 capture at one complex; and (4) continue to build commercial and social partnerships to advance CCUS goals.

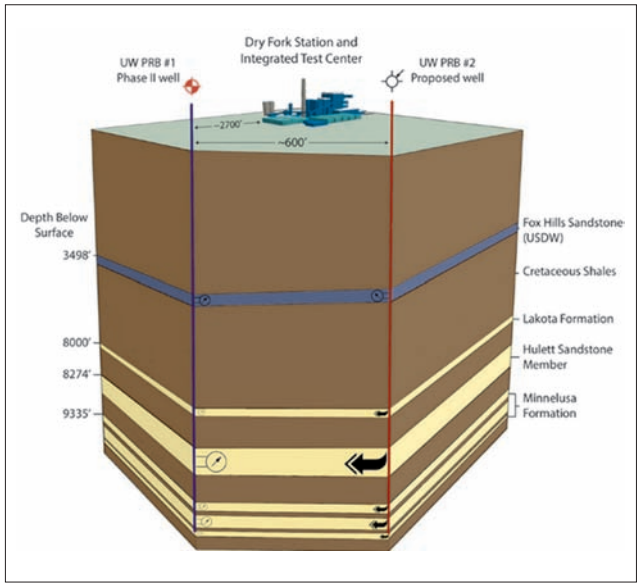


Figure 1 - Location of the injection wells for CarbonSAFE and the Integrated Test Center

Major participants include: CEGR; Basin Electric Power Cooperative; Energy & Environmental Research Center; Advanced Resources International, Inc.; Carbon GeoCycle, Inc.; MTR; Denbury Resources Inc.; Occidental Low Carbon Ventures, UW Enhanced Oil Recovery Institute; UW College of Business; UW College of Law; Los Alamos National Laboratory; and Schlumberger.

Project Update

Drilling and data collection. In July of 2021, the project will complete the fieldwork needed to finalize the geologic site characterization. Fieldwork will consist of drilling a second test well near the test previously drilled a test well. The dual-well system will be utilized to perform injection and monitoring tests to define reservoir performance at reservoir scales. The injection test will use water as the injectate.

UW PRB#1 originally drilled in April of 2019, will be re-entered and serve as the monitoring well. Sidewall core will be collected from zones that were not sampled during earlier phases of the project, such as the lowermost Lakota Formation and lowermost Minnelusa sandstone member. After data collection, UW PRB#1 will be gauged to monitor pressure, temperature, and noise in target injection intervals and other zones of interest during in-situ injection tests (see Fig.1).

UW PRB#2 will serve as a new site point for subsurface data collection and characterization, and as the injection testing well. The well will be drilled to a depth and design that mirrors UW PRB#1 and constructed to meet WYDEQ Class VI requirements. Logging will happen incrementally as the well is drilled.

The log suite will collect geomechanical, wellbore integrity, and geologic data to complete the characterization of the storage site. Sidewall core samples will be collected to bolster core data collected from UW PRB#1 during Phase II. This well will also be the site of in-situ testing.

Baseline Monitoring. Characterization of the stacked storage complex requires the acquisition of baseline conditions. Three baseline datasets will be collected: soil gas, groundwater chemistry, and microseismicity. Multi-season soil gas baselines will be established by continuous monitoring stations deployed at 1 ft to 10 ft below the land surface across the study area over two years. The soil gas monitoring network was deployed in February (2021)

More information

www.wyomingitc.org
www.uwyo.edu/ser
www.xprize.org

Technologies for Direct Air Capture of CO2

Direct Air Capture (DAC) offers a way to mitigate CO2 emissions already in the atmosphere, with the carbon dioxide stored either underground or converted into useful chemicals or materials. Stephen B. Harrison, sbh4 consulting, reviews some of the companies developing commercial DAC solutions.

The worldwide dependency on fossil fuel energy has led to a steady increase in the carbon dioxide (CO2) concentration in the atmosphere in the past 250 years from about 250 ppm to more than 400 ppm. This increase in anthropogenic CO2 concentration is the root cause of the global warming mean temperature increase, which our planet is experiencing. To limit this temperature increase, fossil CO2 emissions into the atmosphere must be reduced to the point of 'net-zero'. Direct air Capture of CO2 can help to accelerate this transition.

Carbon dioxide itself is not harmful to humans, up to a certain concentration. But the steady increase in atmospheric CO2 concentration harms our environment. CO2 removal from the atmosphere is mainly through natural biological processes, in particular photosynthesis in plants where the CO2 is converted to starchy hydrocarbons. Given sufficient time, this process can bind atmospheric CO2 to form other gaseous, liquid, or solid forms of hydrocarbons – most of our fossil resources like oil, gas, and coal were plants million years ago.

Various mechanical direct air capture (DAC) processes have been developed to simulate the action of plants and capture CO2 directly from the air. In the past decade tremendous amount of research has been undertaken to scale up and commercialise these technologies. Each emerging technology has its own advantages, and they are currently at different levels of maturity.

The theoretical minimum specific energy demand for DAC is 150 kWh/Tonne of CO2, but all real-world process operate at a multiple of several times this value. The development challenge is to come as close to this theoretical minimum as possible. The updates presented here highlight several companies and technologies that have made progress in this direction.

Climeworks

Climeworks was founded in 2009 as a Spin-Off from the ETH Zürich. In 2019 they acquired their Dutch competitor Antecy and incorporated their know-how on adsorption. The Climeworks DAC equipment operates a cyclical batch process.

In the first step air is blown through a collector with the help of a fan. Much of the CO2 from the air is captured on the amine-based solid adsorbent in the collector. The CO2 concentration in the exhaust is significantly reduced, but CO2 is not fully captured. Once the adsorbent material is saturated, the collector is heated up to 80°C to 100°C. This releases the CO2 from the solid sorbent. The high purity carbon dioxide is collected and can be processed or sequestered.

Each Climeworks collector can capture up to 50 Tonnes of carbon dioxide per year, assuming a capacity factor of close to 100%. The actual performance is impacted by several parameters, including the ambient conditions and weather at the installation site.

The specific energy demand is 2,000 kWh/Tonne CO2 of low-grade heat and 650 kWh/Tonne of CO2 for electricity, which is mainly required to operate the fan that draws air across the sorbent material. Despite the heat demand being quite large, an advantage of the process is that it only needs heat at low temperature. If this can be recovered as waste-heat from an adjacent chemical or thermal process, the total primary heat demand can be significantly reduced.

Climeworks has sold or operates more than 14 DAC systems of various sizes worldwide. The largest project, with an annual capture capacity of 4,000 Tonnes of CO2, is under construction in Iceland. The captured CO2 will be permanently stored underground when the gas is mineralised to carbonates using the innovative Carbfix process. Heat and power for the system will be supplied from a geothermal power plant to ensure a negative carbon footprint to the overall scheme.

CarbonEngineering

The Canadian-based company, Carbon Engineering was also founded in 2009. Their four-step process starts with a contactor where air is continuously pulled through a large tower and chemically reacts with a potassium hydroxide solution to yield potassium carbonate ($CO_2 + 2KOH \rightarrow K_2CO_3 + H_2O$). In the second step the aqueous potassium carbonate is mixed with calcium hydroxide in a pellet reactor at ambient temperature. This regenerates the potassium hydroxide solution and creates calcium carbonate pellets ($K_2CO_3 + Ca(OH)_2 \rightarrow 2KOH + CaCO_3$).

In the next step the calcium carbonate is thermally decomposed in a classical Calciner at 900°C. This is like the production of lime or cement and releases carbon dioxide ($CaCO_3 \rightarrow CaO + CO_2$).

Unlike classical calciners, the carbon dioxide is not released into the atmosphere, but separated and the resultant high purity carbon dioxide is available for utilisation or sequestration.

The remaining calcium oxide is hydrated in a steam slaker at 300°C ($CaO + H_2O \rightarrow Ca(OH)_2$), and the regenerated calcium hydroxide is fed back into the pellet reactor in step two above.

The specific energy demand varies, depending on the Calciner operating temperature. The total specific energy is around 1,850 kWh/Tonne of CO2 if operated with natural gas heating, or approximately 1,500 kWh/Tonnes CO2 if renewable electricity is used instead of natural gas.

This is a comparatively low specific energy

Geothermal power is ideal to be combined with some DAC technologies

consumption, but the operating temperature is high and the potential to use of waste heat is therefore low. Furthermore, water evaporation within the large air contactor can be very high in dry climate zones. This continuous loss of water must be considered in a full life-cycle analysis.

Carbon Engineering operates a demonstration plant in Canada. A large demonstration plant in the Permian Basin, Texas has been announced, where the captured CO2 will be used for enhanced oil recovery of depleted crude oil fields.

Verdox

A completely different approach to DAC has been implemented by Verdox. The underlying technology developed by Dr. Sahag Voskian at MIT utilises electrochemical cells to capture CO2 from the atmosphere during charging, and releases CO2 when the cells discharge.

The symmetric cells consist of a quinone–carbon nanotube composite. Quinones change their characteristics when an external voltage is applied. This feature is utilised to adsorb CO2 onto the cells in the charging phase.

Several different types of cell have been tested under lab scale conditions to determine their long-term efficacy. The best performing cells have shown a degradation of 30% over 7,000 cycles, which corresponds to just less than 6 months of operation when using a cycle time of 30 minutes.

From a technology maturity perspective, the challenge for this process is to reduce the degradation rate. But the benefits may justify the efforts because the specific energy demand at the cell level is just 568 kWh/Tonne of CO2. If the degradation rate can be reduced by an order of magnitude and thereby extending the cell lifetime to several years, this technology will have great potential.

Verdox has received US$500,000 of funding within the ARPA-E scheme to build a prototype which will be operational in 2022.

Carbyon

Carbyon from the Netherlands, a Spin-Off from TNO, is taking yet another path to innovate an efficient DAC technology. The proposed process is derived from photovoltaic research. It is based on a porous thin-film which is coated with amine- and/or bicarbonate-based adsorbents.

The combination of this thin-film, which is only a few microns thick, and a porous medium could prove to be very energy efficient. The pressure-drop for air to cross the thin, porous medium is very small and the thermal mass of the thin film is low. These factors result in a very low heat demand for the process to capture CO2. The CO2 will be released at a temperature in the range of 65°C to 85°C from the solid-state sorbent.

The company was founded in 2019 and a first demonstration unit is expected to run this year, in 2021. The features of this new approach are very promising, but they must be confirmed at scale.

More information

www.iea.org/reports/direct-air-capture

sbh4.de

Carbon capture in India – webinar report

India could be a giant in the CCS world, with large emissions and enormous CO2 storage potential, and a government keen to meet its Paris targets. But for now, the economics are far from making it viable. Our report from a high level India CCS webinar. By Karl Jeffery. www.ongcindia.com

India could be doing 20 per cent of all the CCUS in the world by 2060, and it needs CCUS to achieve a large part of its Paris targets. But for now, there is nothing to make it financially viable, with no penalty for emitting CO2 in the country. Having a carbon price, and joining an international carbon price scheme, would be a big step forward.

These seemed to be the conclusions from a webinar about CCUS in India on Jan 22nd, organised by India's Oil and Natural Gas Corporation (ONGC). It included senior speakers from India's Directorate General of Hydrocarbons (DGH), Indian Oil Company (IOCL), Oil India and academics from IIM Ahmedabad and IIT Bombay.

From outside India, the webinar had participation from Rystad Energy, OGCI/ Shell, Equinor, Asian Development Bank, Mitsubishi Heavy Industries, IEA and Saudi Aramco.

Amar Nath, Joint Secretary (Exploration), Ministry of Petroleum and Natural Gas, Government of India, said that India's per capita energy consumption is a third of world average, with millions of people living in villages without access to energy.

"Our endeavours are to provide energy to these people. We see energy as a fundamental requirement. It is projected that India will be perhaps the only place where energy growth will continue to take place for the foreseeable future."

"At the same time we are becoming more and more concerned about climate issues. India, as a responsible nation, has already committed itself to taking a lead in the climate issues. The Paris Agreement has already been signed. We are on the track of meeting our target."

"The Prime Minister recently pointed out that India will meet not only its own commitments but the expectations of the world community. We are working on that."

"That is a dilemma. How do we meet our energy requirements, which are dominated by fossil fuels, as well as ensuring climate mitigation methods?"

"One strategy we are adopting is to scale up renewable energy. We have set a target of 450 GW by 2030. But fossil fuels are going to stay as far as we are concerned. The requirement of energy is so much that we need them."

CCUS is "one of the technologies which is being talked about for a long time but has not been able to come to scale. How do we utilise this technology, make it mainstream, so while using fossil fuels, we do not leave a carbon footprint?"

"My belief is India is the place where all kind of experimentation could be done. There are different kinds of fields, you have a wide spectrum of industries available here, you have a huge talent pool available here, we have scientific manpower, we have companies with a global footprint. What is required for scaling of this technology in India?"

Dr C Laxma Reddy, Additional Director General, Directorate General of Hydrocarbons, with the Government of India, said, "We need CCUS to form a key pillar of efforts to put India on the path to net zero emissions."

"CCUS is gaining more significance in the wake of declining crude oil production in India. CO2 EOR is a win-win situation. The oil and gas industry is often in a position to make use of this captured CO2."

"We need to take immediate steps to increase CCS deployment. Policy, technology, market, investments, industry have to work together in a complimentary manner. Government has a critical role."

Amit Garg, Professor, IIM Ahmedabad, said that for India to get to carbon neutrality by 2050 without CCS is "definitely not possible". With CCS, it may be possible to reduce emissions to a level compatible with the Paris agreement, "but with a huge cost."

Vikram Vishal, Professor with university IIT Bombay, has produced a recently updated CO2 storage capacity map for India

Professor Garg was part of the UN's Intergovernmental Panel on Climate Change (IPCC) team which won the Nobel Peace Prize in 2007.

Large amounts of India's economy could possibly decarbonise without carbon capture and storage, he said. For example, the power sector "may be able to manage" if battery storage becomes economically viable. Transport would need to shift from road to rail and use renewable power – electric vehicles and biofuels. Growing biofuels would provide many farmers with an income. The forestry sector could become net negative with CO2, if trees outside forests can be allowed. But that still leaves plenty of industrial emissions.

Professor Garg's team have mapped out the whole of India for CO2 large point sources, storage sites, oilfields where CO2 could be injected, and sites which can be used for EOR. It also includes areas where there could be more forestry.

He estimates that if the carbon price can reach $60 a tonne (2005 prices) it should be viable to do carbon capture for 780m tonnes CO2 a year in India. The market could be

linked to other markets internationally. "If carbon prices come in, I'm very sure industrial businesses, if they see a [way to make a financial] killing, they will go for it."

"We need large scale industrial CCUS demonstration projects, we need it pretty quickly," he said.

Vikram Vishal, Professor with university IIT Bombay, said India has many deep saline aquifers where "tens to hundreds of gigatons" of CO2 could be stored.

Prof Vishal's team has recently updated a "capacity map" for CO2 storage in India, the first update since the IEAGHG report in 2008.

By 2060, 20 per cent of all the industrial CCUS in the world could be in India, he said. To get there, work needs to be done connecting CO2 sources with CO2 reservoirs, identifying the reservoir with the lowest risk and the right capacity.

Indian Oil Corporation

Dr SSV Ramakumar, director of research and development with IOCL (Indian Oil Corporation Ltd), said that IOCL is developing enzymatic CO2 capture, lacing normal amine solvents with a biological catalyst (enzyme). It has developed a solvent this way which is stable up to 150 degrees C, and can absorb 2.1x as much CO2 as normal amine.

The temperature the solvent needs to be heated to, to disassociate the CO2, is reduced from 140 degrees C to 90 degrees C, so the operating costs are lower.

Research is going into methods of converting the captured CO2 into useful material. "We have a plethora of pathways of biochemical, bio fermentation, algal combination, bio-electrochemical," he said. IOCL is working with a company called LanzaTech to find ways to combine aerobic processes together.

One idea is to convert CO2 to acetates, which are themselves low value-added chemicals, but which can be used as sugars for algae. The algae generates high value fuels similar to diesel, called lipids, and maybe also high value Omega acids, which have a "value of thousands of dollars per kg depending on purity."

IOCL has a 10 Kg / day CO2 pilot plant. "We are gung-ho about this technology", he said.

IOCL is also researching biochemical routes, which could convert ethanol to more valuable butanol.

It has a "very aspirational" project with India's oil company ONGC to capture CO2 in a refinery in Gujarat, and then transport it to an oilfield for EOR injection.

Oil India

Saloma Yomdo, chief general manager reservoirs with Oil India Ltd, discussed how CO2 EOR could be viable in northeast India, the main oil and gas producing area in India.

The prize could be another 13.7m m3 (86m barrels) of additional oil, enhancing the recovery from the top 10 reservoirs by 5 per cent, equivalent to 4 years of production levels, he said

But there is no obvious CO2 source in the area – it does not have the level of heavy industry seen in other parts of the country, such as the North and West.

Northeast India is a very tectonically active zone, with highly heterogenous, compartmentalised reservoirs. There are about 180 single well reservoirs, with depths of 3000 to 5000m.

Oil India has found that by injecting low salinity water, it can improve recoveries by 10 to 15 per cent. The deeper Eocene reservoirs in particular have good permeability. So with low salinity water it is possible to achieve recoveries of over 50 per cent. But this raises the question of whether using CO2 would improve recovery much further.

But the main issue driving commercial success is the cost of CO2 capture and transportation. Another big challenge is that many of the fields are 50 to 60 years old, and their equipment has not been designed for CO2 EOR. Also there is not much expertise in CO2 EOR in the area.

A possible source of CO2 is Brahmaputra Cracker and Polymer Limited (BCPL), a public sector company. It is currently venting CO2 to the atmosphere. There is also a Memorandum of Understanding with Indian Oil Company to look at capturing CO2 from the Digboi refinery, Assam, which was built in 1901.

A candidate reservoir has been studied in detail with a simulation, together with the University of Houston, and approved for a pilot trial.

Another possibility is to do a trial with carbonated water injection – water with 10 per cent CO2 - but the company floated the idea in an "Expression of Interest" and received no response, he said. The carbonated water could form carbonic acid, leading to corrosion problems.

"If anybody has any experience with carbonated water injection, we would be very happy to talk to them," he said.

Mr Yomdo emphasised that CCS projects generally need government support to get started. For example, the Petra Nova project had $400m funding from the US Department of Energy, $300m from the government of Japan, and $300m from NRG, the company running the coal plant. "For mega projects like CCUS in India, tremendous support will be required from the government."

Rystad, OGCI, Equinor advice

Speakers from Rystad Energy, OGCI, Equinor, ADB and Mitsubishi had some advice about how India can move faster on carbon capture, and how they might be able to contribute

Jarand Rystad, CEO, Rystad Energy, has calculated that the average cost of the full chain for CCS is $200 per tonne, based on projects already operational.

Speaking at the webinar about CCUS in India, he said that if CCS costs $200 a tonne, it means that Norway is the only country in the world with plans to bring in a carbon price high enough to make CCS viable. It plans to gradually increase the cost of emitting up to $230 a tonne, he said.

"So far in India, it is zero cost of emitting CO2. Then there is not a business case for companies to do [CCS]".

Oil companies in India "should have the courage to support politicians in forcing a carbon tax. It should be introduced early but [kept] predictable, so it doesn't trigger too much uncertainty. A linear increase to $200 in 20 years could be very bold but very efficient. Before you see that carbon tax, I don't see this [CCS] will take off."

And while power generation and transport could theoretically be powered by renewable electricity, CO2 would still be emitted by in-

dustrial processes where the CO2 molecule is created as part of that process, such as cement. That is 7 or 8 GT of CO2 a year globally, of which 2.5 GT is emitted in India, he calculates.

"One new technology I haven't heard anyone talk about is capturing the carbon molecule," he added. "There are some new technologies with pyrolysis of methane, we have direct capturing of black carbon. The molecule of CO2 is 44, carbon is 12. This is one place where we have seen some research which could change the picture."

OGCI

Iain Macdonald, CCUS Workstream Lead, Oil and Gas Climate Initiative, seconded from Shell, said that OGCI is supporting a number of CCUS hubs around the world which it perceives to be "kick starters", helping get a cluster of industries around them in action.

"We've seen in the last few years a shift of 'point source to sink single project,' to understanding the economies of scale of operating on a hub," he said. Hubs "help to de-risk things, facilitate the economics to come through."

It means different CO2 emitters can share the same CO2 storage site. CO2 storage is then accessible to companies which don't have subsurface expertise, and oil and gas companies, which do have subsurface expertise, can apply it to multiple industries.

OGCI has set an objective to help five emerging hubs reach operations and help identify and mature future hubs in "a number of additional countries".

Hubs which OGCI considers to have a "defined concept" are Net Zero Teesside (UK), Northern Lights / Longship (Norway), Rotterdam (Netherlands), and China Northwest. Hubs which it is evaluating and considers to be "high potential" are Texas (USA), Louisiana (USA) and Edmonton (Canada).

CO2 emitting industries which are part of the hubs include biomass power, gas power, waste incineration, fertilisers, petrochemicals, hydrogen, cement, steel, aluminium and refineries. The hubs can also accept CO2 imports.

Equinor

Norway's "Northern Lights" CO2 storage project is now fully approved, and will be in operation in 2024, with 3 equal owners, Equinor, Shell and Total, said Per Sandberg, Senior Advisor, Equinor Low Carbon Solutions. Mr Sandberg is also leader of business development for Northern Lights.

The project was initiated by the Norwegian government, which also provided 80 per cent of the funding.

There is no real technical innovation, because CO2 storage is already well proven, he said. But the commercial model is innovative, offering services to accept and store CO2. This service is otherwise not available in Europe.

"Any industrial company who is located near a harbour within reasonable shipping distance from our [Bergen] facility, they are a potential customer," he said.

Northern Lights is having "serious conversations" with over 50 European companies (or global companies with European plants), about providing CO2 to the scheme, and he estimates that ultimately 10-15 will provide CO2.

The challenge for its customers is having financial justification to participate, when it is more expensive to store CO2 then emit it, even with a European carbon price. 11 potential customers have applied for government funding support.

The world will ultimately want to see hundreds of projects like this, he said. It can form a grid similar to the electricity and gas grids.

It helps that Norway has a "rich government, which made a lot of money out of oil and gas," he said. "They are putting in a substantial investment for this Longship, almost $2bn." [Longship is the name of the full chain project, also involving CO2 capture].

"A crucial aspect, which was the toughest part of the decision, was to prove there is a future for CCS. That's the one we have struggled most with. "Being able to tell a little bit about progress on the commercial side is very crucial."

"What we have learned from the commercial work is that there is no magic bullet. You need to collect and combine several types of value, and several types of improvement."

Perhaps India could also incorporate CO2 import with its onshore CO2 storage. "That's a way to get the cost down," he said.

ADB

CCUS related work by the Asian Development Bank includes assessing India's policy framework for CCUS, publishing information about prospects, making a CCUS road map for China, and assisting China and Indonesia to establish carbon capture centres of excellence, said Dr Pradeep Perera, Principal Energy Specialist, Asian Development Bank.

In 2018-2019 it helped Indonesia to draft a carbon sequestration law. In 2020 it organised webinars on CO2 mineralisation and "game changing CCU technologies."

It assessed whether carbon capture could be applied on a 250 megawatt Integrated Gas Combined Cycle (IGCC) power plant in Tianjin, China.

It has worked on the Yanchang CCUS demonstration project in China, which is expected to be China's first full-chain, fully-integrated financially viable project, and the Gundih gas field CCS pilot project in Indonesia, where it has supported the government of India in doing a feasibility study.

Mitsubishi

Mitsubishi Heavy Industries has carbon capture technology on 12 commercially operating plants, in the US, Malaysia, Japan, India (4 plants), Bahrain, UAE, Vietnam, Pakistan, and Qatar, said Takashi Kamijo, Project Manager, Licensor Director, Mitsubishi Heavy Industries.

Its technology is on the world's largest CO2 capture plant, Petra Nova in Texas, in operation since 2016, capturing 4776 tonnes per day.

It has two more under construction. One in Russia planning to come onstream in 2021 capturing 1200 tonnes per day, and one in Bangladesh coming onstream in 2022, capturing 240 tonnes per day.

The process has been gradually improved over the past 30 years, starting with work to screen solvents in 1990, working with Kansai Electric Power Company, with a bench scale test. Its first commercial plant was in operation in 1999, capturing 200 tonnes CO2 per day. After that, it did one commercial deployment roughly every 2 years.

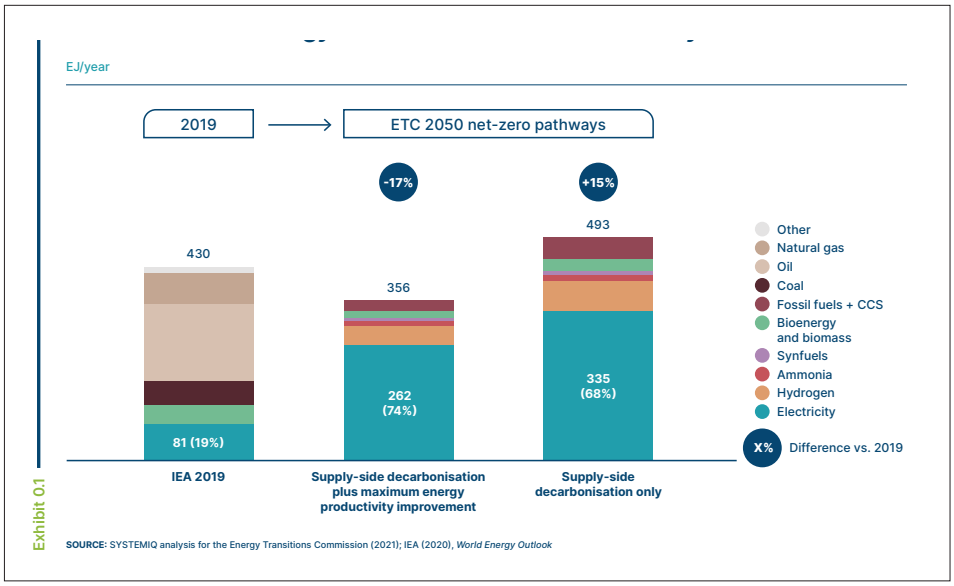
Clean electrification and hydrogen can deliver net-zero by 2050

The Energy Transitions Commission (ETC) has released two new reports analysing the feasibility of achieving a net-zero greenhouse gas emissions economy by 2050.

Clean electrification will be at the heart of this transformation enabled by the rapidly falling costs of renewable energy, with a complementary role for clean hydrogen technology in sectors that are difficult or impossible to electrify.

The report Making Clean Electrification Possible: 30 years to electrify the global economy sets out why it is essential but also feasible and affordable to multiply the size of the global power system by 5, while shifting to renewable-based electricity provision.

The parallel report Making the Hydrogen Economy Possible: Accelerating clean hydrogen in an electrified economy sets out the complementary role for clean hydrogen and how a combination of private-sector collaboration and policy support can drive the initial ramp up of clean hydrogen production and use to reach 50 million tonnes by 2030.



Indicative final energy mix in a zero-carbon economy (From "Making Clean Electrification Possible")

Net zero by 2050 is possible

The Paris climate accord committed the world to limiting global warming to less than a 2°C increase from pre-industrial levels — and striving for no more than a 1.5°C rise in the planet's average temperature. For this objective to be reached, the world needs to achieve net-zero GHG emissions by around mid-century.

The ETC states that achieving a net-zero GHG emissions economy within the next 30 years is technically and economically feasible. A profound transformation of the global energy system is ahead – a net-zero GHG economy will be built on abundant, affordable zero-carbon electricity.

Pace of renewables deployment to be multiplied by 5-7 times by 2030

Electricity could represent up to 70% of final energy demand by 2050, versus 20% today, with total electricity use expected to grow as much as 5 times in the coming decades. Transitioning to clean electricity as the main source of final energy represents the cheapest and most efficient way to decarbonise the economy. The rapidly falling costs of renewables and storage solutions make it possible to achieve the required massive expansion of clean power systems at low cost, according to the reports.

However, wind and solar must increase from today's 10% of total electricity generation to about 40% by 2030, and over 75% by 2050. Annual wind and solar installations must therefore grow by 5-7 times by 2030, and more than 10 times by 2050. They must also be accompanied by the parallel deployment of other zero-carbon generation technologies (like hydro and nuclear), flexibility solutions, storage and power networks to deliver zero-carbon power systems at scale.

The ETC states that this is undoubtedly within reach if clear national strategies for decarbonisation are put in place and appropriate power market design unlocks private financial flows. Investments in renewable power, primarily wind and solar, will represent the vast majority (around 80%) of total investments required to achieve a net zero economy.

Over $80 trillion of investment will be required globally over the next 30 years (ca. $2.5 trillion per annum on average). This includes investment in renewable generation to support both direct and indirect electrification, in addition to investment in electricity grid infrastructure. Whilst large, this represents less than 1.5% of global GDP and is manageable in the current macroeconomic environment.

Clean hydrogen production costs to be brought well below $2/kg by 2030

Clean hydrogen will play a complementary role to decarbonise sectors where direct electrification is likely to be technologically very

challenging or prohibitively expensive, such as in steel production and long-distance shipping. A net zero GHG emissions economy by mid-century will likely need to use about 500 to 800 million tonnes of clean hydrogen per annum, a 5-7 fold increase compared to hydrogen use today.

Green hydrogen, produced via the electrolysis of water, is likely to be the most cost-competitive and therefore the major production route in the long-term, due to falling renewable electricity and electrolyser equipment costs. It could account for approximately 85% of total production by 2050. However, blue hydrogen, produced from natural gas with carbon capture (with 90%+ capture rates) and low methane leakage (<0.05%), will play an important role in transition and in some specific very low-cost gas locations.

The report highlights how critical rapid ramp-up of production and use in the 2020s is to unlock cost reductions (bringing clean hydrogen costs below $2/kg) and to make mid-century growth targets achievable. However, even once clean hydrogen becomes cheaper than grey hydrogen, using hydrogen in different industry and transport sectors will often still impose a "green cost premium" compared to current high-carbon technologies.

Public policy is therefore essential to drive uptake of clean hydrogen at pace. Policymakers will also need to anticipate growing hydrogen transport and storage needs. In total, 85% of investments required to ramp-up hydrogen production is for renewable electricity provision (included in the renewables investment above). Additionally, ca. $2.4 trillion ($80 billion per annum) will be required between now and 2050 for hydrogen production facilities and transportation & storage.

Critical milestones to be reached by 2030 to put 2050 targets within reach

"We now have the technologies to completely decarbonise electricity generation at low cost: and electrification is the key to zero carbon production in most of the economy. By mid-century even rich developed countries will need 2-3 times as much electricity as today, and developing economies 5-10 times as much. Governments, businesses and investors need to recognise the scale of the new industrial revolution required and the huge opportunities it creates," Lord Adair Turner, Chair, ETC.

With regards to power, the ETC recommends that developed countries should achieve grid emissions intensity below 30gCO2/kWh by the mid-2030s and developing countries by the mid-2040s. To achieve those medium-term objectives, critical actions in the 2020s include:

• Clear national medium-term targets for power decarbonisation and for the electrification of the economy

• Appropriate incentives for renewables deployment at scale, including power market design encouraging private investment, with a continued role for long-term contracts

• Unlocking financial flows for investment in developing countries, including via blended finance vehicles

• Anticipating the build-up of network infrastructure and capabilities required for simultaneous mass electrification and power system decarbonisation

• Planning and permitting processes that accelerate implementation

• Developing the technologies and business models of the future, especially for long-term energy storage and flexibility provision

"The ETC demonstrates that rapid decarbonisation of the global power system is desirable, attainable and affordable. It's the bedrock of the Race to Zero emissions and provides the expansion of zero carbon power needed for other sectors to also decarbonise. The ETC highlights how countries setting out clear strategic plans for electrification and decarbonisation will enable companies and innovators to deliver the massive increase in clean power needed," Nigel Topping, UK High Level Climate Action Champion, COP26

Meanwhile, public policy needs to pull forward clean hydrogen demand in the 2020s to drive production volumes up (reaching 50 million tonnes by 2030). This requires a rapid decarbonisation of hydrogen production for already existing uses and accelerated technology development, piloting and early adoption of hydrogen in other key sectors with lower levels of technology readiness but large potential demand, like steel, shipping and synthetic aviation fuels. Instruments to achieve that early demand growth, while supporting the scale-up of clean hydrogen supply, include:

• Carbon pricing to create broad incentives for decarbonisation

• Sector-specific policies to create demand for low-carbon technologies, and financial support mechanism for investment and to overcome the "green cost premium" challenge

• Targets for the development of large-scale electrolysis manufacturing and installation

• Public support and collaborative private-sector action to bring to market key technologies

• Developing hydrogen industrial clusters to enable the simultaneous development of hydrogen production, storage, transport and end-use, de-risking investments for all players involved

• Establishing rules and standards on safety, purity and GHG-intensity of hydrogen

"Clean hydrogen will be key to decarbonising sectors where direct electrification is impossible or too expensive. Steel can be made zero carbon using hydrogen as the reduction agent; ocean-going ships will likely burn ammonia made from green hydrogen: and hydrogen can provide electricity when the wind isn't blowing and the sun not shining. In total the world may need to produce and use 5-7 times as much hydrogen as today, and there are no inherent barriers to achieving that. But strong public policy support and visionary private investment is needed to drive clean hydrogen growth at the fast pace now required," Lord Adair Turner, Chair, ETC.

"Green hydrogen made from renewable electricity will be the best complement to deep electrification to achieve a sustainable and decarbonised energy sector. It will bring investment opportunities and qualified jobs, while making our economy cleaner and more competitive. Policy commitments to scale up this new economy are necessary and will bring important economic and environmental benefits in the years to come," Agustin Delgado, Chief Innovation and Sustainability Officer, Iberdrola.

The ETC is a coalition of more than 45 leaders from global energy producers, energy industries, financial institutions and environmental advocates – including ArcelorMittal, Bank of America, BP, Development Research Center of the State Council of China, EBRD, HSBC, Iberdrola, Ørsted, Shell, Longi Solar, Tata Group, Volvo Group and the World Resources Institute.

More information

www.energy-transitions.org

Applying CCS to the UK waste sector

The UK waste sector sees CCS as an essential component to getting to net zero, applying it to waste incineration plants, we heard at a CCSA webinar. By Karl Jeffery.

The UK recycling and waste sector sees CCS as an essential component of its net zero plans, connecting it to waste incineration plants, said Tim Rotheray, director of innovation and regulations at Viridor, a UK recycling, resource and waste management company.

He was speaking at a webinar organised by the Carbon Capture and Storage Association (CCSA) on Apr 21, "The Role of CCUS in Decarbonising the UK Economy".

The accounting for greenhouse gas in waste and recycling is complex. Landfill itself does not emit any CO2, although the rotting of food waste and clothing from natural fibres gives off methane. If waste designated for landfill is sent instead to a waste incineration plant with CO2 captured, that is not directly saving any CO2 emission.

Waste recycling is good for the environment in that it removes the need to produce new steel, glass and plastic. But the waste sector does not benefit from this. "For every plastic bottle that is recycled, you reduce emissions by 50 per cent, but that benefit accrues to another part of the economy," he said.

Meanwhile, recycling activities themselves use a lot of energy, with transport, sorting and finally thermal treatment to recover something which can be re-used. This is added to the waste sector's carbon balance sheet.

As of 2020, about 50 per cent of all UK waste goes into landfill. The amount which is recycled is a huge improvement from 1990, when there was hardly any recycling in the UK. But it has also reached a plateau, it is hard to see how recycling can be further improved, he said.

And of course the waste sector does not have control over the material it receives. It cannot control issues such as how well people wash out a yoghurt pot or milk bottle before recycling, and so how much food waste gets into the recycling system, causing contamination and biogenic emissions.

Policy

The UK waste sector is entirely driven by policy. The customers are nearly all local councils, and everything is done according to standards set by government.

Speakers at the CCSA webinar. Top row: Tim Rotheray, director of innovation and regulations, Viridor; Luke Warren, CEO CCSA. Bottom row: Ana Musat, head of policy, Aldersgate Group; Sonia Krylova, Head of industrial decarbonisation strategy, BEIS

The UK's government advisory group Climate Change Committee has recommended that biogenic material going to landfill should be stopped by 2025. "That's something we would support," he said.

So in order to further decarbonise, the waste sector would look to reduce anerobic material in landfill, reduce or decarbonise transport, reduce the fossil energy required for recycling and for thermal treatment of recycling. But the policies to achieve these do not yet exist, he said.

Mr Rotheray presented analysis by the UK government into emissions by different sectors and their contribution to the economy through payroll and corporation taxes.

The subtext is that the government is looking at how much money industrial sectors contribute to the country when deciding how much emissions they should be allowed to make.

The waste sector was shown to be the fifth largest emitter of greenhouse gas in the UK. It is "at the lower end" in terms of its payroll tax contribution, but not the lowest, he said.

It is not impacted by emission trading schemes, because there is no requirement for the waste sector to purchase carbon credits for emissions in the UK.

There are many consultations in government about how to improve recycling rates from the current 50 per cent. "The target is 65 per cent. The Climate Change Committee is calling for that to be 70 per cent."

There will always be some "residual waste" which cannot be recycled.

"Business as usual - driving up recycling - is not going to get us where we want to get to. Emissions will barely drop. So we've got a big problem facing the sector in terms of delivering our emission reduction," he said.

Carbon capture

There are only two technologies which enable residual (non-recyclable) waste to be treated with zero emissions – landfill or incineration / energy recovery with carbon capture.

So one important pathway is to build incineration / energy recovery plants with carbon capture on them.

At the moment there are 41 energy recovery facilities in the UK, taking about 50 per cent of non-recyclable waste. "CCUS for this industry is absolutely critical", he said.

"We need to start delivering CCUS in this decade to ramp up the scale of deployment that is needed across the sector."

"The amount of engineering work that needs to be done, the physical securing of planning - doing the pipeline of activity, means we need to get moving quite quickly," he said.

"Having looked at a site, and looked at the sheer scale we're talking about, the risk is we say, 'we can wait a few years.' I don't think we have time for that."

"The opportunity is about scaling and modularisation. If we can create a scalable market which creates a proper investment cycle which people can continue to expand, that will be the thing which drives down cost."

"The engineering expertise of doing this is broadly understood. But bringing it together in an effective way, so you can do it in a rapid modular way and cost effectively, that's where the opportunity lies. All the parts of the jigsaw come together, you can appraise, invest and build."

"If we deliver that kind of retrofit, we will create a real skills export market for the rest of the world," he said.

But first, we need accelerated government targets to drive it.

It is possible that some investment in CCS could be recouped through being able to sell carbon credits to other companies. "Carbon pricing clearly has a role to play, but it doesn't, on its own, make a difference enough to enable the investment."

Experience has shown that low carbon technologies only became investable through instruments like the Contract for Difference (CFD), which give investors certainty about their returns over the lifetime of the project.

"The incredible success of CFD and the reason it has been copied is because it has driven down the cost of capital by giving bankable contracts," he said.

"The trading scheme doesn't do that. The ability to get bankability is critical in driving down the cost and getting us to a subsidy free world."

The UK waste sector also has the benefit of being able to see some of the work done on waste + CCS in Norway and the Netherlands. "We're really fortunate that some other countries have taken the plunge and done some of the really difficult challenges," he said. "We can use that [experience] - and we should."

More information

The video of the webinar is online here

vimeo.com/542759173

BECCS at Drax can save the UK £4.5 Bn

Developing bioenergy with carbon capture and storage (BECCS) at Drax could save the UK energy system and consumers billions of pounds over the next decade, according to a new report.

The independent analysis by leading energy consultancy Baringa, commissioned by Drax Group, evaluates the impact of deploying BECCS at scale as part of achieving the country's climate change targets.

It finds that without BECCS at Drax Power Station the energy system would incur additional costs of around £4.5bn to achieve the UK Government's fifth carbon budget in 2028 to 2032 – making decarbonisation more difficult and significantly more expensive.

Will Gardiner, Drax Group CEO, said, "Innovative green technologies like BECCS can save the UK billions of pounds in achieving our legally binding climate targets, whilst removing millions of tonnes of CO2 from the atmosphere and supporting tens of thousands of jobs."

"Drax is ready to invest in this essential technology which will help the UK decarbonise faster and kickstart a whole new industry here. By delivering BECCS, the UK can show the world what can be achieved for the environment and the economy when governments, businesses and communities work together."

Not developing BECCS at Drax, or more widely across the country, will also have significant costs for the UK reaching its net zero by 2050 target. The report estimates the target will cost £15bn more to achieve without deploying this essential negative emissions technology.

With the right investment framework from government, work to build Drax's first two BECCS units could get underway as soon as 2024, ready to start capturing and storing millions of tonnes of CO2 a year in 2027.

Drax BECCS in 2027 is "no regrets" in all scenarios

Baringa explored the role of BECCS-Power in driving cost-optimal pathways to meet net zero using three scenarios: Central, Downside and Upside, to test the role of BECCS-Power under different conditions.

In all scenarios, the decarbonisation pathway is lower cost if BECCS at Drax is deployed in 2027.

Two Drax biomass units (derated from 630 MW to 460 MW) are converted to BECCS in 2027-29 in all three scenarios. An additional 1 – 9 GW of new build BECCS is added from 2030 – 2050.

In all cases, it is cost-effective to run the BECCS capacity at high load factors for a significant part of the pathway. In the last 10 years, some biomass is used for to BECCS hydrogen production, and BECCS in power operates more flexibly to complement intermittent renewables.

More information

www.drax.com

Projects and policy news

NextDecade to develop CCS LNG project

www.next-decade.com

NextDecade will develop one of the largest carbon capture and storage projects in North America at its Rio Grande LNG project.

Under a new subsidiary, NEXT Carbon Solutions, the CCS project is expected to reduce permitted CO2 emissions at Rio Grande LNG by more than 90 percent without major design changes to the Rio Grande LNG project. As a result, Rio Grande LNG is expected to be the greenest LNG project in the world.

NEXT Carbon Solutions' CCS project at Rio Grande LNG is expected to enable the capture and permanent geologic storage of more than five million tonnes of CO2 per year. NEXT Carbon Solutions believes that developing the CCS project at the same time as the Rio Grande LNG project will result in 60-80 percent less capital costs than retrofitting an operating LNG facility.

All-in costs of the CCS project, including capital and operating expenses, interest, transportation, and permanent storage, are expected to be $63 to $74 per metric tonne of CO2 before any benefit from Section 45Q tax credits.

Including the full benefit of Section 45Q tax credits, the breakeven cost of adding CCS to Rio Grande LNG is expected to be $13 to $24 per metric tonne of CO2 or $0.05 to $0.09 per MMBtu on an LNG basis. Coupled with its low costs, NextDecade believes that LNG from Rio Grande LNG will be among the greenest and most attractively priced in the world.

Rio Grande LNG in Texas is expected to be the greenest LNG project in the world with the use of CCS and NEXT Carbon Solutions' proprietary processes

AUD $400 million available to South Australia for emission reduction

www.pm.gov.au

The Commonwealth will contribute funding funding for investment in priority areas such as carbon capture and storage, electric vehicles, hydrogen and other emissions reduction projects in South Australia.

The Morrison and Marshall Governments have signed a $1.08 billion State Energy and Emissions Reduction Deal that will deliver secure, reliable and affordable energy to South Australians and help Australia continue to meet and beat its emissions reduction targets.

Under the agreement, the governments will pursue initiatives that create additional dispatchable generation to help deliver affordable and reliable power, unlock gas supplies to help prevent shortfalls in the market, kick-start works on a new interconnector between South Australia and New South Wales, and invest in key emissions reduction projects.

The Commonwealth will contribute $660 million and South Australia will provide $422 million as part of the agreement.

Key components of the deal includes $400 million in Commonwealth funding for investment in priority areas such as carbon capture and storage, electric vehicles, hydrogen and other emissions reduction projects in South Australia to help meet and beat Australia's commitments under the Paris Agreement;

Prime Minister Scott Morrison said the bilateral agreement is a key part of delivering on the Government's plan to ensure South Australians get a fair deal on energy, businesses get the affordable energy they need to create jobs and Australia meets our emissions reduction targets to address climate change.

Equinor and SSE Thermal to build CCS and hydrogen power stations

www.equinor.com

Equinor and SSE Thermal have unveiled plans to jointly develop two first-of-a-kind, low-carbon power stations in the UK's Humber region.

This includes the UK's first power stations with carbon capture and storage technology, and the world's first 100% hydrogen-fuelled power station.

The plans, underpinned by a new cooperation agreement between the two companies, would support the UK's transition to net zero and accelerate the decarbonisation of the Humber, the UK's largest and most carbon-intensive industrial cluster. The projects have the potential to create thousands of skilled jobs and revitalise a key industrial heartland.

The two decarbonised power stations, which would form a 'clean power hub' near Scunthorpe, North Lincolnshire, would be among the first in the world to utilise CCS and hydrogen technologies.

Keadby 3 and Keadby Hydrogen would replace older, carbon-intensive generation on the electricity grid, providing flexible and efficient power to support intermittent renewable generation and maintain security of supply through the net zero transition.

These projects would also result in the Humber making a significant contribution to the UK's 2030 targets for CCS and hydrogen. Keadby 3 could deliver 15% of the target for 10MT of carbon captured annually by 2030, while the demand from Keadby Hydrogen could account for a third of the 5GW hydrogen production goal.

Keadby 3 would be a 900MW power station fuelled by natural gas and fitted with carbon capture technology to remove the CO2 from its emissions. The captured CO2 would then be transported using shared pipelines before being securely stored under the Southern North Sea.

A formal consultation for Keadby 3 concluded in early 2021 and the project is currently progressing towards the submission of a development consent application in Spring 2021. Keadby 3 would have the potential to come online by 2027, in line with Government ambitions for 'Track 1' industrial cluster projects.

Keadby Hydrogen power station would have a peak demand of 1,800MW of hydrogen, producing zero emissions at the point of combustion. It would be the world's first major 100% hydrogen-fired power station, securing at-scale demand for hydrogen in the region for decades to come. With appropriate policy mechanisms in place, Keadby Hydrogen could come online before the end of the decade.

The Keadby 3 and Keadby Hydrogen projects are both in the development stage and the companies will continue to engage government, regulators and stakeholders. Final investment decisions will depend on the progress of policy frameworks that are commensurate with the delivery of this critical net zero enabling infrastructure.

The projects would use the parallel hydrogen and CO2 pipeline infrastructure being developed by the Zero Carbon Humber (ZCH) partnership – which includes Equinor and SSE Thermal – and offshore CO2 infrastructure developed by the six-member Northern Endurance Partnership (NEP), which includes Equinor. Both ZCH and NEP won public funding from the UK's Industrial Strategy Challenge Fund in March.

Equinor's H2H Saltend project will be the first to connect into the ZCH infrastructure and will come online by the mid-2020s. Like the additional hydrogen that would be produced for the Keadby Hydrogen project, H2H Saltend will provide low-carbon hydrogen to already-identified customers.

As part of the agreement SSE Thermal and Equinor are also developing options for hydrogen blending at SSE Thermal's Keadby 2 project (already under construction), aiming to progressively decarbonise the UK's newest and most-efficient power station. The companies also have the intention to collaborate on projects elsewhere in the UK.

Unilever, LanzaTech and India Glycols launch laundry capsule made from carbon emissions

www.unilever.com
www.lanzatech.com

Unilever has partnered with LanzaTech and India Glycols to produce a surfactant made from industrial carbon emissions instead of from fossil-fuels.

The shift in production uses biotechnologies and a newly configured supply chain between the three partners, who are working together for the first time. Typically derived from fossil fuels, surfactants are a critical ingredient for creating the foam and cleaning action of many household cleaning and laundry products, from dish soaps to fabric detergents. The new process now allows surfactants to be made using recycled carbon.

Recycled carbon is a key form of renewable carbon and is essential to eliminating the use of fossil fuels. A recent report published by the Nova Institute and Unilever in April 2021 estimates that demand for fossil-derived chemicals will more than double by 2050. Renewable carbon production will need to increase by a factor of 15 by 2050 to phase-out the use of fossil carbon in consumer products.

The process marks the first time a surfactant made using captured carbon emissions will come to market in a cleaning product. The new surfactant will be used in an OMO (Persil) laundry capsule, which will launch in China on April 22nd, World Earth Day. The product will come at no extra cost to consumers.

The breakthrough process involves primarily three stages:

• Capture: LanzaTech uses biotechnology to capture waste industrial emissions at its Beijing Shougang LanzaTech plant in China and converts these emissions to ethanol.

• Conversion: India Glycols Ltd converts the ethanol into ethylene oxide, a key feedstock to make surfactants at their site in India.

• Formulation: Unilever uses the surfactant in the new OMO laundry capsules, manufactured at its Hefei factory in China.

Leading oil & gas investment firm embraces CCS

carboninfrastructurepartners.com

JOG Capital, a private equity firm with a 14-year track record managing more than $1.3 billion in energy investments will rebrand as Carbon Infrastructure Partners (CIP).

CIP is among the first investment firms focused on solving the dual challenge of how to meet global energy demand for 7.7 billion people while rapidly reducing carbon emissions.

CIP believes the solutions to these challenges lie in understanding and investing in the entire carbon lifecycle; from hydrocarbon-based energy production through to carbon capture, utilization, and storage back into the subsurface.

The business and investment opportunity for CCS arises from this technology that returns carbon to the ground and is experiencing regulatory tailwinds and bi-partisan support both in the U.S. and Canada.

This represents a paradigm shift, as the U.S. government subsidizes the capture and storage of carbon to incentivize and encourage net zero commitments -- which we believe represents version 2.0 of viable, actionable, and tax-advantaged climate solutions.

Furthermore, we believe rapidly growing demand for high-quality voluntary carbon offset credits, combined with significant additional policy incentives, activates business models for carbon removal assets to directly remove CO2 from the atmosphere.

"As established oil and gas investment professionals, we understand the full lifecycle of carbon and we seek to be market leaders on climate-driven carbon management to meet global energy demands while rapidly reducing carbon emissions," said Craig Golinowski, President and Managing Partner of CIP.

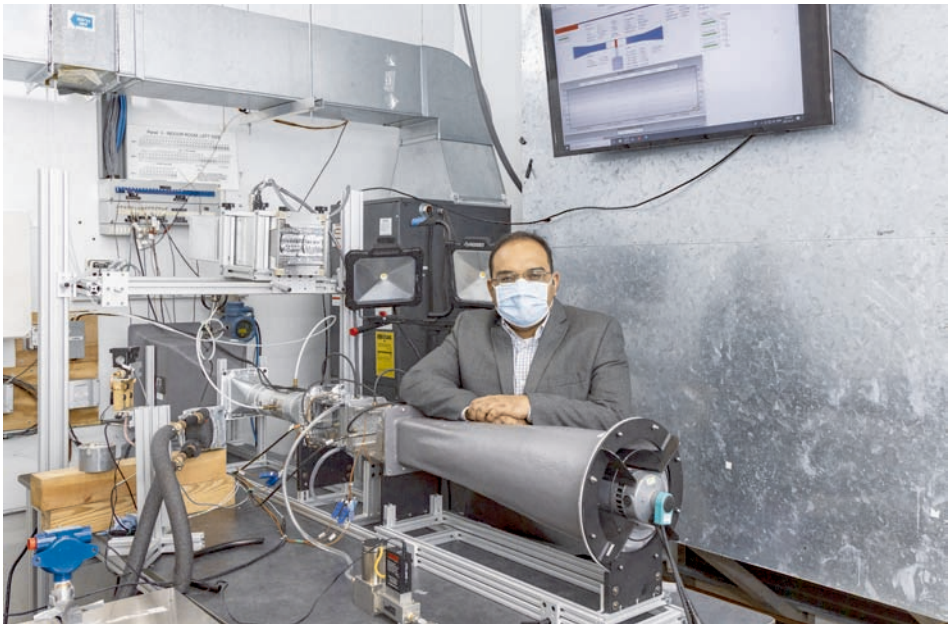
Redesigning building equipment for carbon capture and beyond

Kashif Nawaz, a mechanical engineer who leads the newly formed Multifunctional Equipment Integration Group at ORNL, is designing a carbon capture platform for incorporation into existing rooftop heating and air conditioning units on commercial and residential buildings.

When Kashif Nawaz looks at a satellite map of the U.S., he sees millions of buildings that could hold a potential solution for the capture of carbon dioxide. With an estimated 120 million buildings dotting the landscape of the nation, it's no small invention if Nawaz's approach fully demonstrates its viability over the next few months.

Focused on direct air capture, Nawaz's research represents what he calls a shift in how the scientific community has traditionally thought about ways to manage carbon dioxide emissions, whose climbing levels have the potential to upset the delicate balance of ecosystems, contributing to extreme weather patterns and crop loss.

"We know that carbon dioxide levels aren't decreasing and we're beginning to see the effects," Nawaz said. "Providing an economical, easy-to-implement solution to mitigate it is perhaps the greatest challenge we've faced in our lifetime."



Kashif Nawaz, researcher and group leader for multifunctional equipment integration in buildings technologies, is developing a platform for the direct air capture of carbon dioxide that can be retrofitted to existing rooftop heating, ventilation and air conditioning units. Photo: ORNL/U.S. Dept. of Energy

Traditionally, scientists have looked at capturing carbon emitted from a specific source, such as the gases from coal power plants. Nawaz, however, is focused on taking it out of a source that's constantly around us every day — the atmosphere.

"My idea is to leverage something that already exists to solve a global problem and extract the carbon from the air — a source you can't directly see like an industrial application," he continued. "We know that more than 10 million rooftop heating, ventilation and air conditioning units exist in the U.S. that can be retrofitted with carbon capture capabilities. Eventually, my vision is this can be extended to residential platforms as well. The possibilities aren't far from being reality."

As an awardee of UIUC's alumni teaching fellowship, Nawaz also taught heat transfer to undergraduate students. Through gaining experience with extensive heating, air conditioning, ventilation and refrigeration manufacturers who served on the industrial advisory board of UIUC's Air Conditioning and Refrigeration Center, Nawaz became keenly interested in novel materials and manufacturing techniques which can enable unprecedented solutions.

"For example, I discovered that a surface area metal foam can revolutionize the design practices for heat exchangers," he said. "Complex structures can enable a highly compact design without compromising the efficiency, and many of these innovations are inspired by nature."

It's these type of possibilities Nawaz went on to investigate when he took on a professional role in the corporate world with Johnson Controls, serving as a senior heat transfer engineer after graduation. It was there in their Heat Transfer Center of Excellence that he developed energy efficient solutions for split residential and commercial packaged units. Nawaz said working for industry has given him a unique perspective and impacted his current research at ORNL.

"We are taught about great concepts at universities without much appreciation for real life constraints; you can have a unique design, but it has to be affordable," he said. "I've seen firsthand what it really takes to apply these big ideas on the industry side and for industry to adopt them."

More information

www.ornl.gov

Capture and utilisation news

PNNL researchers develop lower cost CO2 capture solvent

www.pnnl.gov

The new solvent reduces costs by 19 percent compared to current commercial technology and requires 17 percent less energy.

In a study published in the March 2021 edition of International Journal of Greenhouse Gas Control, researchers from the U.S. Department of Energy's Pacific Northwest National Laboratory—along with collaborators from Fluor Corp. and the Electric Power Research Institute—describe properties of the solvent, known as EEMPA, that allow it to sidestep the energetically expensive demands incurred by traditional solvents.

"EEMPA has some promising qualities," said chemical engineer Yuan Jiang, lead author of the study. "It can capture carbon dioxide without high water content, so it's water-lean, and it's much less viscous than other water-lean solvents."

At a cost of $400–$500 million per unit, commercial technology can capture carbon at roughly $58.30 per metric ton of CO2, according to a DOE analysis. EEMPA, according to Jiang's study, can absorb CO2 from power plant flue gas and later release it as pure CO2 for as little as $47.10 per metric ton, offering an additional technology option for power plant operators to capture their CO2.

Jiang's study described seven processes that power plants can adopt when using EEMPA, ranging from simple setups similar to those described in 1930s technology, to multi-stage configurations of greater complexity. Jiang modeled the energy and material costs to run such processes in a 550-megawatt coal power plant, finding that each method coalesces near the $47.10 per metric ton mark.

Toshiba's carbon recycling technology realizes world's highest CO2 conversion speed

www.toshiba.com

The CO2 electrocatalyst electrode stack technology can convert up to 1.0 ton of CO2 a year at ambient temperatures, with an installation space the size of an envelope.

Toshiba Corporation has developed the world's most efficient electrocatalyst technology for converting carbon dioxide into carbon monoxide, a raw material for fuel and chemicals. The electrocatalyst has an installation area about the size of a C5 envelope, operates at room temperature, and can process up to a ton of CO2 a year. This dramatic improvement in processing speed and conversion rate was achieved with a proprietary technology for stacking CO2 electrocatalyst electrodes.

Previous attempts to stack electrolytic cells only slowed the processing speed. Toshiba's proprietary stacking technology eliminates such lower speeds, and dramatically improves CO2 conversion rate. Since this new approach increases processing speed per unit of area, it can be applied to locations with space limitations. For example, an incineration plant that releases 200 tons of CO2 a day would require an installation area of 2,000m2, roughly the area of 5 basketball courts. Tests to date also indicate that the stack can be scaled up, a major factor for bringing it much closer to commercialization.

Toshiba will promote scaling up and system demonstration of the CO2 electrolysis stack technology, aiming to commercialize P2C technology that uses renewable energy to recycle CO2 in the late 2020s.

HeidelbergCement and Fortera collaborate on CCS pilot in California

www.heidelbergcement.com

www.forterausa.com

HeidelbergCement's US subsidiary Lehigh Hanson and materials technology company Fortera will pilot a new type of carbon capture and utilisation (CCU) technology at Lehigh's Redding California cement facility.

Both partners will construct and operate a small commercial plant where CO2 will be captured from the kiln exhaust and converted into a cementitious material with an expected 60% reduction in CO2 emissions per tonne of product. The final product will be suitable for use as a new low carbon SCM (Supplementary Cementitious Material) in the production of high-quality concrete with a lower CO2 footprint.

Lehigh Hanson Redding Cement Plant, Redding, California. Fortera's product will be the first cementitious material produced commercially from carbon dioxide captured directly from a cement kiln

"We are delighted to add yet another technology to our existing portfolio of carbon capture initiatives, contributing to the circular economy", says Dr. Dominik von Achten, Chairman of the Managing Board of HeidelbergCement. "Carbon capture and utilisation or storage (CCU/S) is one key lever to significantly reduce otherwise unavoidable greenhouse gas emissions in the cement industry. This is why building new partnerships towards CCU/S and investing in breakthrough technologies are a core part of HeidelbergCement's climate strategy."

The product generated within the new carbon capture process at the Redding plant will be the first cementitious material produced commercially from CO2 captured directly from a cement kiln. Fortera's proprietary recarbonation (ReCarbTM) process works by tapping into the existing feedstock and equipment at the plant, while production carries on as usual from the quarry to the kiln.

Instead of then releasing CO2, the kiln exhaust is captured and mineralized into a cementitious material. The material can be co-blended with portland cement and used by ready mixed concrete producers as a Supplementary Cementitious Material (SCM) or as a cementitious binder for preformed concrete materials like bricks, blocks or precast structures.

The collaboration with Fortera aims to prove the commercial scalability, the quality of the final product, and the competitive economics of the technology.

Transport and storage news

Northern Lights and Borg CO2 collaborate on CCS solutions

www.norlights.com
www.borgco2.no

They have signed a Memorandum of Understanding to explore the feasibility of CO2 capture, transport and storage solutions for industrial partners in the Fredrikstad region.

Borg CO2 is a joint project between 18 industry partners and the port of Borg, which will serve as host for a future CO2 loading terminal. The plan is to transport captured CO2 to this terminal, where it will be loaded onboard a Northern Lights operated ship for transport to the intermediate storage terminal at Øygarden on the Norwegian west coast.

From Øygarden the CO2 will be injected into a 100 km long pipeline and injected into permanent storage in a reservoir 2.6 km below the seabed.

Borg CO2 is developing a carbon capture and storage (CCS) solution for emissions from industrial facilities in Fredrikstad, Sarpsborg and Halden. The industrial cluster employs 1,400 people and is responsible for emissions of almost 700,000 tonnes of CO2 annually. The aim is to capture and store up to 90% of the total emissions, or around 630,000 tonnes a year.

Northern Lights delivers CO2 transport and storage as a service and aims to enable the decarbonisation of industrial emissions and to facilitate the removal of CO2 from the air. The company is a joint venture between partners Equinor, Shell and Total.

Borg CO2 is currently completing a feasibility study involving 18 industrial partners, representing process industry, waste management, logistics, energy, technology providers and academia. It is supported by CLIMIT, a national programme for research, development and testing of CCS technologies.

DNV updates CCS recommended practicecontracts

www.equinor.com

DNV has published new procedures designed to provide the required safety level in transporting CO2 by pipelines and strengthen the development of CCS projects.

The updated recommended practice follows the outcome of the CO2SafeArrest joint industry project (JIP) between Energy Pipelines CRC (Australia) and DNV. The work has been supported by the Norwegian funding body CLIMIT and the Australian Commonwealth Government under the Carbon Capture & Storage Research Development and Demonstration Fund.

The JIP involved two large-scale CO2 crack arrest tests being carried out on 24" pipelines to better understand the safety implications of CO2 releases. The testing was performed at the DNV Research and Development facility in the UK.

The work has been supported by the Norwegian funding body CLIMIT and the Australian Commonwealth Government under the Carbon Capture & Storage Research Development and Demonstration Fund.

The need to transport CO2 is expected to increase significantly in the years to come as part of the widespread view that CCS is a viable means to reduce CO2 emissions. Reliable transport from where it is captured to a storage site is therefore of utmost importance.

An updated recommended practice (RP), DNVGL-RP-F104 Design and operation of carbon dioxide pipelines, has been published based on the results from the CO2SafeArrest JIP, resulting in a new empirical model for the assessment of running ductile fractures in CO2 pipelines. The RP can also be used alongside DNVGL-ST-F101 Submarine Pipeline Systems.

Transport of CO2 can be done either through the use of existing pipelines or the construction of new pipeline systems. DNVGL-RP-F104 is supporting both the design of new pipelines and the reuse of existing infrastructure by describing a process of how to re-qualify the pipelines for CO2 transport through various steps. Requirements for re-qualification is primarily identified through a change of medium in the pipeline, for example, from natural gas as in the original design, to CO2.

Both for new CO2 pipelines and re-qualification of existing pipelines, the operators of the pipelines need to fully understand the threats, failure mechanisms, consequences and probabilities of pipeline failures in order to ensure that they are operated safely.

Cquestr8 raises $300k seed capital to develop 'safe & permanent' carbon storage

cquestr8.com

Cquestr8, 2020 winners of the Climate-KIC's ClimateLaunchpad "Next Big Thing" prize, has secured funding to develop carbon capture using natural processes to safely lock away CO2 as stable ocean bicarbonate.

Cquestr8 solutions target hard to decarbonise sectors including cement, lime, and steel production. Funds will be deployed toward proof of concept development, ahead of customer engagement in 2022. Cquestr8 is working with the University of Malaya, Nottingham University and other partners on extensive validation of the reaction engineering and marine environment benefits.

Steve Willis, co-founder of Cquestr8 said, "The world will need many carbon removal and sequestration channels to keep the atmospheric temperature rise below 1.5 °C and yet still keep essential industries operating."

"We are excited that our scalable solution will deliver 100% measurability, 1000 year+ permanence and significant environmental co-benefits, all at a very low cost. This investment helps us turn 2 years of research and design work into an engineering prototype supported by robust environmental science."

Andrew Shebbeare, Managing Partner at Counteract, said, "We get particularly excited by carbon removal applications with systemic benefits."

"The Cquestr8 team combines deep chemical engineering expertise with extreme care for the natural environment and is uniquely placed to develop a product not only combating the climate emergency but also helping sustain marine ecosystems."

"We believe their idea can reach Gigaton scale, with a host of practical customer applications from point source to direct air capture. We're excited to support them in the next phase of their business' evolution."

CO2 injection phase complete at Otway project

CO2CRC has announced the successful completion of the safe injection of CO2 into a saline formation 1.5km below ground at the Otway International Test Centre (OITC) in Nirranda South, Victoria.

This is a major milestone in CO2CRC's Otway Stage 3 Project which is developing next generation subsurface CO2 monitoring and verification technologies for application in commercial carbon capture and storage (CCS) projects.

The CO2 has been safely injected deep into the subsurface, marking the end of field operations for the Otway Stage 3 Project. A total of 15,050 tonnes of CO2 was injected, bringing the total volume of CO2 safely and securely stored at the OITC since commencement of operations in 2007 to just over 95,000 tonnes.

CO2CRC and site operator, UPS, maintained their exemplary health, safety and environment (HSE) record at the OITC. No lost time injuries were recorded for the whole operations campaign, meaning 14 years of operations without a lost time injury.

"With the field operations phase of the Otway Stage 3 Project completed successfully, we now turn our full attention to the scientific deliverables of the project," said David Byers, Chief Executive of CO2CRC.

"The monitoring and verification technology infrastructure now in place at the OITC provide significant improvements in data collection and processing time and allow the scientists to track an image of the CO2 plume on demand as it moves through the storage reservoir.

"Working with our partners CSIRO, Curtin University, and the University of Sydney we will analyse the data and conduct detailed techno-economic studies on the Stage 3 technologies. We aim to validate our initial estimates of the potential for monitoring cost reductions of up to 75 percent for commercial scale CCS projects," he said.

Key to the success of field operations has been the involvement and support received from local landowners and the Nirranda community who have been consulted and kept informed of project developments over the last five years.

"We thank local landholders and community members. Without the continuing support of our local community, this world leading scientific research would not be possible" he said.

The $45 million Otway Stage 3 project is jointly funded by the Commonwealth Government's Education Investment Fund (EIF), Low Emissions Technology Australia (LETA) through ANLEC R&D, BHP and the Victorian State Government.

More information

co2crc.com.au

Wärtsilä highlights potential for marine CO2 scrubbers and liquid CO2 transport

Initial findings show that CCS on ships is technically viable for the sector to pursue. The company has also secured approval in principle for a cargo containment system for liquid CO2 carriers.

Wärtsilä Exhaust Treatment has highlighted the potential for exhaust gas abatement systems to directly tackle maritime carbon dioxide emissions in the near future, as technology advances and enables manufacturers to design and upgrade scrubbers to capture carbon at the point of exhaust.

Wärtsilä has conducted extensive research and development to explore how Carbon Capture and Storage can be developed and scaled in the maritime sector. To further accelerate development, Wärtsilä is installing a 1MW pilot plant at its test facility in Moss, Norway. This pilot plant will allow the company to test its CCS technologies in a range of scenarios and conditions.

CCS, enabled by scrubbers, must take a central role within the suite of solutions helping to drive decarbonisation in shipping, including alternative fuels and efficiency technologies, the company said. As there is not only one single solution on shipping's environmental impact the sector must innovate broadly across multiple areas.

"Building on the success of existing and well-proven technologies, such as scrubbers, will be vital to succeeding on the industry's decarbonisation goals," said Sigurd Jenssen, Director, Exhaust Treatment at Wärtsilä. "Exhaust gas abatement technologies have reached a point of maturity where it is only right that we explore their wider applications beyond sulphur compliance."

Given the scale of the decarbonisation challenge ahead, Wärtsilä Exhaust Treatment believes there is no better place to focus the efforts than on the biggest emission of them all – carbon – and think about the ways that we can use what we have already learned from sulphur, both as an organisation and as an industry.

Jenssen added: "CCS onboard vessels is clearly a substantial undertaking, but one that we believe we are well placed to pioneer. Carbon capture is exciting because it can provide significant reductions in a relatively short timeframe. This is important in the context of the industry's overall decarbonisation transition, as it will enable us to safeguard existing assets as we move to a cleaner mode of operating."

Wärtsilä Exhaust Treatment offers integrated compliant solutions for all types of ships, and in open loop, closed loop or hybrid configurations. Wärtsilä's scrubbers are built with a modular approach to future technology development, creating a platform for the abatement of other emissions from shipping beyond sulphur.

CO2 liquid transport

Wärtsilä Gas Solutions has developed a cargo tank design suitable for LCO2 applications, which was recently awarded Approval in Principle (AiP) by the classification society DNV. Since new LCO2 Carriers are an emerging concept and requires detailed attention during conceptual level, Wärtsilä's experience and know-how in gas cargo and handling systems proved invaluable to the results.

The total cargo capacity of the vessels is 7500 cbm, divided into two containment tanks, each of 3750 cbm. Wärtsilä has carried out an intensive engineering analysis to formulate an optimum design for the vessels' containment system and cargo handling systems, bearing in mind the specific nature of LCO2.

"Liquid CO2 is increasingly relevant in global efforts to reduce greenhouse gas emissions and promote a greener future," said Pål Steinnes GM Sales, Wärtsilä Gas Solutions.

"It represents an important link in the value chain for the entire carbon capture infrastructure. In developing a robust and proven concept, both in the cargo containment and cargo handling requirements for LCO2 Carriers, we have drawn on our unparalleled experience in gas carrier segments. The AiP from DNV is a valuable endorsement of this work."

"We have been pleased to work with Wärtsilä Gas Solutions on this reliable design concept. The review process has been extensive, and we trust that their solution will contribute to facilitating the trade in liquid CO2 as a factor in reducing emission" says Monika Johannesen, Head of Department, Gas Carrier Excellence Center at DNV.

More information

www.wartsila.com

Carbfix builds a CO2 Mineral Storage Terminal in Iceland

Industrial emitters in Northern Europe can now store their CO2 in Iceland where it will be injected into the basaltic bedrock and turned into stone via the Carbfix technology.

The preparation phase for the Coda Terminal, a CO2 Mineral Storage Terminal, is now underway. The Terminal will be based in the bay of Straumsvík, in South West Iceland, and will be equipped to receive large quantities of CO2 transported by ship. At full scale, the Coda Terminal will provide an annual storage amounting to three million tonnes of CO2.

Edda Sif Pind Aradóttir, CEO of Carbfix, said, "The Coda Terminal will launch a new climate-friendly industry that is based on innovative solutions and up-scaled climate action. By receiving CO2 from neighbouring countries for permanent mineral storage, Iceland takes on a pioneering role within Europe."

The Coda Terminal will receive CO2 transported by specifically designed ships operating on sustainable fuel. The transport of CO2 to Iceland is enabled by the low costs associated with onshore mineral storage. In fact, the Coda Terminal will be the first large scale geological storage project in Europe that is carried out onshore.

The Carbfix technology will then be used to permanently and safely turn CO2 into stone, deep within the basaltic bedrock. The Terminal will also be able to store CO2 from local industries, as well as CO2 captured directly from the air (DAC).

The nature of mineral storage operations allows for a gradual build-up of the site with minimal risk. The Coda Terminal will be constructed in three phases, with a full-scale capacity of three million tonnes of CO2 annually.

The preparation phase will begin in 2021 with engineering and permitting processes. Drilling of the first wells will start in 2022, with the aim of commencing operations in 2025 and reaching full scale by 2030.

Nature stores vast quantities of CO2 in rocks. The Carbfix process accelerates this natural process by dissolving CO2 in water before injecting it deep underground, where it turns into solid minerals in less than two years. The only feedstock for the process is water, electricity, CO2 and reactive rock formations such as basalts, and the entire on-site operations will run on renewable energy.

As part of the CarbFix project gases from the Hellisheidi Geothermal Power Plant are captured in a dedicated water scrubbing tower with an annual capacity of about 15,000 tonnes of CO2 and injected into basaltic formations at >400m depth where the fluid reacts with the bedrock and forms stable carbonate minerals in less than two years.

"The environment in Straumsvík, with its fresh basaltic lavas and vast sources of groundwater streams, is perfectly suited for permanent and safe CO2 mineral storage.

The power requirements are minimal, and the transmission grid and an industrial harbour are already in place," says Aradóttir, adding that the storage capacity is more than sufficient, as Carbfix geologists estimate that Iceland alone could store around 80-200 times the annual global emission of CO2.

The Icelandic parliament recently adopted the EU's CCS Directive to comply with safe transport and storage of CO2 in Iceland. The legislation enables emitters that fall under the Emission Trading System (ETS) to use the Carbfix technology to reduce their emission.

"The Directive has created an incentive for companies to adopt innovative carbon capture and storage technologies, like Carbfix. The price of emission allowance has increased rapidly lately and currently sits at about €42/tonne."

"This is significantly higher than the costs associated with Carbfix's ongoing CCS project in Iceland. We are quite certain that the cost of storage at the Coda Terminal will be considerably lower than €20/tonne."

More information

www.carbfix.com

CarbonBuilt's CO2 trapping concrete has won the NRG COSIA Carbon XPRIZE