Carbon Capture Journal

CCUS in Australia

Carbon Capture absorbent development at CSIRO Energy

Santos CEO calls on Australia to be 'CCS superpower'

Australia invests $50 million in six projects

July / Aug 2021 Issue 82

Mitsubishi: enabling the future of CCUS on the route to Net Zero

- Increasing hydrogen storage effectiveness on the path to net zero
- Carbon Capture from cement production through mineralisation
- Unlocking private finance to support CCS investments
- Pembina and TC Energy partner on 'world-scale' CCS project

Net Zero by 2050: a roadmap for the global energy sector

In a new flagship report, the International Energy Agency lays out the path to achieve a net zero global energy system, but warns it is narrow and requires an unprecedented transformation of how energy is produced, transported and used globally.

Climate pledges by governments to date – even if fully achieved – would fall well short of what is required to bring global energy-related CO_2 emissions to net zero by 2050 and give the world an even chance of limiting the global temperature rise to 1.5 °C says the report, "Net Zero by 2050: a Roadmap for the Global Energy Sector".

The report is the world's first comprehensive study of how to transition to a net zero energy system by 2050 while ensuring stable and affordable energy supplies, providing universal energy access, and enabling robust economic growth. It sets out a cost-effective and economically productive pathway, resulting in a clean, dynamic and resilient energy economy dominated by renewables like solar and wind instead of fossil fuels.

The report also examines key uncertainties, such as the roles of bioenergy, carbon capture and behavioural changes in reaching net zero.

"Our Roadmap shows the priority actions that are needed today to ensure the opportunity of net-zero emissions by 2050 – narrow but still achievable – is not lost. The scale and speed of the efforts demanded by this critical and formidable goal – our best chance of tackling climate change and limiting global warming to 1.5 °C – make this perhaps the greatest challenge humankind has ever faced," said Fatih Birol, the IEA Executive Director.

"The IEA's pathway to this brighter future brings a historic surge in clean energy investment that creates millions of new jobs and lifts global economic growth. Moving the world onto that pathway requires strong and credible policy actions from governments, underpinned by much greater international cooperation."

The CCUS contribution

A failure to develop CCUS for fossil fuels could delay or prevent the development of CCUS for process emissions from cement production and carbon removal technologies, making it much harder to achieve net-zero emissions by 2050, says the report.

The report shows how CCUS can facilitate the transition to net-zero CO_2 emissions by: tackling emissions from existing assets; providing a way to address emissions from some of the most challenging sectors; providing a cost-effective pathway to scale up low-carbon hydrogen production rapidly; and allowing for CO_2 removal from the atmosphere through BECCS and DACCS.

In the Net-Zero Emissions by 2050 Scenario (NZE), policies support a range of measures to establish markets for CCUS investment and to encourage use of shared CO_2 transport and storage infrastructure by those involved in the production of hydrogen and biofuels, the operation of industrial hubs, and retrofitting of existing coal-fired power plants.

Capture volumes in the NZE increase marginally over the next five years from the current level of around 40 Mt CO_2 per year, reflecting projects currently under development, but there is a rapid expansion over the following 25 years as policy action bears fruit. By 2030, 1.6 Gt CO_2 per year is captured globally, rising to 7.6 Gt CO_2 in 2050.

Around 95% of total CO_2 captured in 2050 is stored in permanent geological storage and 5% is used to provide synthetic fuels. Estimates of global geological storage capacity are considerably above what is necessary to store the cumulative CO_2 captured and stored in the NZE. A total of 2.4 Gt CO_2 is captured in 2050 from the atmosphere through bioenergy with CO_2 capture and direct air capture, of which 1.9 Gt CO_2 is permanently stored and 0.5 Gt CO_2 is used to provide synthetic fuels in particular for aviation.

Energy-related and process CO_2 emissions in industry account for almost 40% of the CO_2 captured in 2050 in the NZE. CCUS is particularly important for cement manufacturing.

Although efforts are pursued in the NZE to produce cement more efficiently, CCUS remains central to efforts to limit the process emissions that occur during cement manufacturing. The electricity sector accounts for almost 20% of the CO_2 captured in 2050 (of which around 45% is from coal-fired plants, 40% from bioenergy plants and 15% from gas-fired plants).

CCUS-equipped power plants contribute just 3% of total electricity generation in 2050 but the volumes of CO_2 captured are comparatively large. In emerging market and developing economies, where large numbers of coal power plants have been built relatively recently, retrofits play an important role where there are storage opportunities.

In advanced economies, gas-fired plants with CCUS play a bigger role, providing dispatchable electricity at relatively low cost in regions with cheap natural gas and existing networks. In 2030, around 50 GW of coal-fired power plants (4% of the total at that time) and 30 GW of natural gas power plants (1% of the total) are equipped with CCUS, and this rises to 220 GW of coal (almost half of the total) and 170 GW of natural gas (7% of the total) capacity in 2050.

A further 30% of CO_2 captured in 2050 comes from fuel transformation, including hydrogen and biofuels production as well as oil refining. The remaining 10% is from DAC, which is rapidly scaled up from several of pilot projects today to 90 Mt CO_2 per year in 2030 and just under 1 Gt CO_2 per year by 2050.

More information

www.iea.org

Carbon Capture Journal

July / Aug 2021 Issue 82

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

Editor
Keith Forward
editor@carboncapturejournal.com

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

Subscriptions
subs@carboncapturejournal.com

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

Carbon Capture Journal is your one stop information source for new technical developments, opinion, regulatory and research activity with carbon capture, transport and storage.

Carbon Capture Journal is delivered on print and pdf version to a total of 6000 people, all of whom have requested to receive it, including employees of power companies, oil and gas companies, government, engineering companies, consultants, educators, students, and suppliers.

Subscriptions: £250 a year for 6 issues. To subscribe, please contact Karl Jeffery on subs@carboncapturejournal.com Alternatively you can subscribe online at www.d-e-j.com/store

Front cover:

BECCS technology at Drax Power Station supplied by Mitsubishi Heavy Industries – MHI plans to locate its core CCS team at the company's European headquarters in London (pg. 10)

Back cover: CSIRO's Ambient CO2 Harvester based on cooling tower technology for contacting and use of an amino-acid based absorbent (pg. 2)

Carbon capture journal (Print) ISSN 1757-1995
Carbon capture journal (Online) ISSN 1757-2509

Leaders - CCUS in Australia

Projects and policy

Capture and utilisation

Transport and storage

Carbon Capture absorbent development at CSIRO Energy

CSIRO has been researching amine absorbent technology for over fifteen years - here we chart its progress through to large scale and long-term pilot testing and commercial viability. By Graeme Puxty, Research Team Leader Energy and Paul Feron, Group Leader, CSIRO.

In the beginning...

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) is Australia's national science agency of about 5,500 scientists, engineers, and support staff. It is organised into Business Units that each focus on specific areas. In around 2004, the what is now called CSIRO Energy Business Unit recognised the role carbon capture technologies could play in mitigating carbon dioxide (CO2) emissions from fossil fuel based energy generation and industry.

Initially, a broad program of research was undertaken encompassing: the use of aqueous amines (both known and synthetically novel), ionic liquids, enzymes and adsorbents; pilot plants for testing of capture materials, process modifications and process performance; and assessments of environmental impacts of process emissions.

Over time, as knowledge was gained, the energy sector changed, and commercial viability was assessed, the most promising areas were prioritised with some research phased out and new areas introduced as shown in Figure 1.

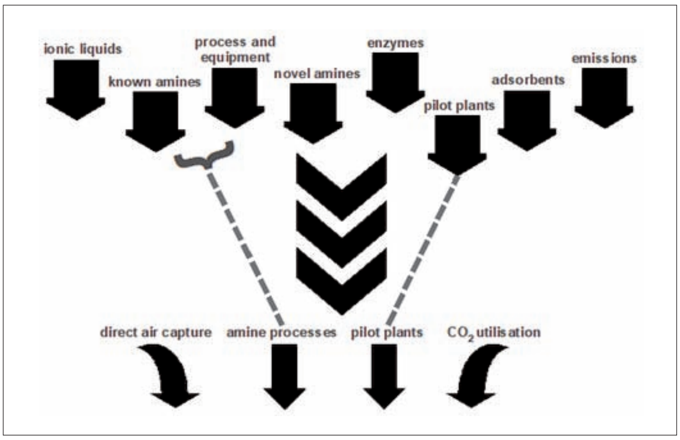


Figure 1 - From an initial very broad research program CSIRO Energy has now rationalised its focus to the areas shown

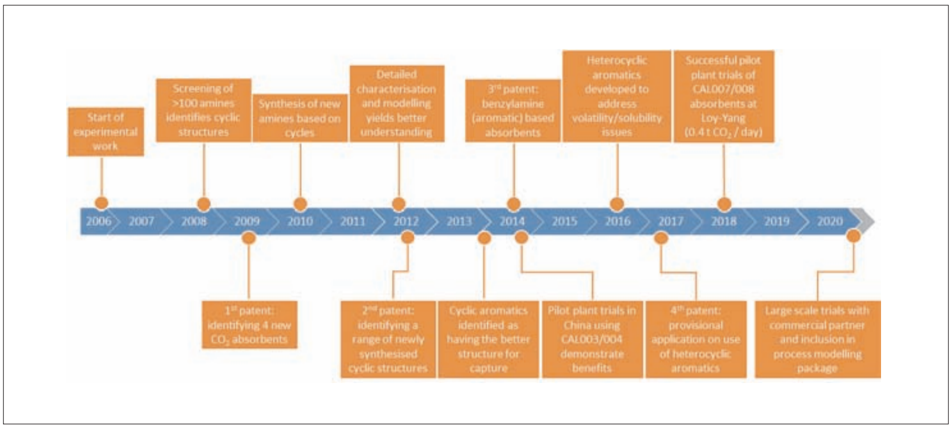


Figure 2 - A timeline of the aqueous amine absorbent development work undertaken by CSIRO Energy

The focus of this article will be the development of aqueous amine based absorbent technology that has progressed from early stage bench research through to large scale and long-term pilot testing and commercial viability. Its lineage can be traced back to the work started in 2004 and is tightly entwined with numerous pilot plant campaigns that have both validated the research and thrown up new unexpected challenges

Amine based absorbent development

A timeline of aqueous amine based absorbent development work is shown in Figure 2.

The rationale for focus in this area was to develop absorbents of improved performance that could be readily used in existing carbon capture processes. Similarly to the broad based research program undertaken, initially the research strategy involved the development and application of a method based on differential scanning calorimetry to rapidly determine the absorption capacity and rate of CO2 absorption at fixed conditions from very small samples of a very large range of amines.

Over 100 commercially available amines were evaluated, and the resulting data analysis indicated heterocyclic amines stood out as a class with appealing performance.[1] Heterocyclic amines were then identified as the focus for our further research both for commercially available amines and as the structural blueprint for synthesis of novel amines.

A range of heterocyclic amines were investigated in greater detail through the determination of reaction kinetics and mass transfer by stopped-flow and wetted-wall techniques, vapour-liquid-equilibria (VLE), and chemical speciation used NMR and infrared spectroscopies. This led to several patent applications based on commercially available and synthetically novel heterocyclic amines. They were consistently found to offer a mixture of large

1. *The results from a large proportion of this initial study were published in G. Puxty, et al., Carbon dioxide post combustion capture: a novel screening study of the carbon dioxide absorption performance of 76 amines. Environmental Science & Technology, 43 (2009) 6427-6433.*

CO_2 absorption capacity and fast reaction kinetics.

However, a drawback of heterocyclic amines is the propensity of secondary amino groups to form nitrosamines in the presence of nitrous oxides in gas streams. This was particularly relevant in Australia where flue gas streams do not typically have denitrification technology installed. Further research into primary amines that also contain cyclic structures identified primary amines with aromatic functionality as particularly promising.

Aromatic amines

Aromatic amines as considered in our work consist of an aromatic ring with a pendant primary alkyl amino group. These compounds include some of the benefits of the heterocycles, but with some differences. They maintain fast reaction and mass transfer, but they don't have quite as large net CO_2 absorption capacity.

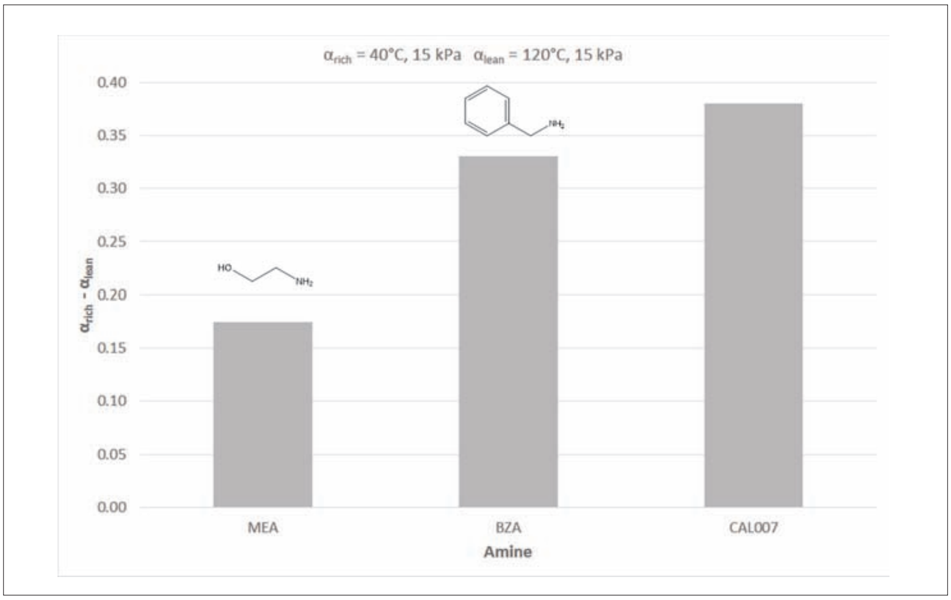


Figure 3 - Cyclic capacity as the difference in equilibrium liquid CO_2 loading (mol CO_2 / mol amine) between rich conditions (40°C, 15 kPa CO_2 partial pressure) and lean conditions (120°C, 15 kPa CO_2 partial pressure) for MEA and aromatic amines BZA and CAL007 all at 5 mol/L total amine concentration

However, their structural rigidity means they have greater cyclic capacity via reduced degrees of structural freedom resulting in more of the energy input for CO_2 stripping going towards disrupting the bonding of CO_2. This is illustrated in Figure 3 which compares the cyclic capacity of monoethanolamine (MEA), archetypal aromatic amine benzylamine (BZA) and an improved aromatic amine codenamed CAL007.

These aromatic amines also exhibit unique chemical stability afforded by the aromaticity, with only the pendant arm being reactive in a way that allows degradation to be suppressed. Besides characterising the typical absorption performance parameters, understanding how oxidative degradation of these types of amines can be controlled has been the focus of our most recent research.

This has now reached the point where not only can the rates of degradation be reduced to very low levels, but the main degradation pathway that does occur is reversible.

Pilot plant trials, tribulations and successes

Operations in pilot plants have proven invaluable to both validate the performance of the absorbents under development and to highlight their inadequacies as well. CSIRO Energy has operated a range of pilot plant campaigns in its small in-house pilot (20 kg CO_2 / hour) using synthetic gas mixtures, and in larger pilot plants located at three different coal fired power stations in Australia's eastern states. Initial testing of BZA in CSIRO's in-house pilot identified good capture performance but also some unexpected operational issues.

At high concentration BZA forms a solid product upon reaction with CO_2. It was observed that BZA vapour would readily lead to pipework blockages in the overhead section of the stripper. While it could be managed, this triggered further work to reduce the BZA vapour pressure through the use of additives, and alternatively through the study of BZA derivatives.

It was found that BZA derivatives offered a viable option that maintained all the favourable properties of BZA, while eliminating the operational challenges. One of these derivatives, known as CAL007, was selected for a long-term trial in a 50 kg CO_2 / hour pilot plant designed and constructed by IHI Corporation (Japan) and operated on a brown coal flue gas slip stream at AGL's Loy Yang power station in the state of Victoria. Incidentally, this was also the location of CSIRO's first pilot plant that in 2008 captured CO_2 from power station flue gas for the first time in the southern hemisphere.

The trial suffered an initial setback, with unanticipated loss of CAL007 occurring at an unacceptable rate. Fantastic team work between the engineers operating the plant and scientists responsible for the absorbent resulted in a modified formulation dubbed CAL008 (still aromatic amine based).

This formulation was successfully operated for 5,000 hours without reclamation in a challenging environment, with oxygen concentrations in the inlet gas on average at about 10% and capture efficiency maintained at >80% for the bulk of the campaign.

Amine consumption during the campaign was an order of magnitude smaller than 30wt% MEA and the formulation was unaffected by nitrous oxides (present at 150 – 180 ppm). The minimum reboiler duty achieved was 2.6 GJ / tonne CO_2, although values of <2.5 GJ / tonne CO_2 are achievable in a plant specifically designed for operation with CAL008[2].

Other pilot plant campaigns have been previously reported in the Carbon Capture Journal which reflect the broad pilot plant design and operating capability that has been developed at CSIRO. These include:

• Campaigns using MEA and concentrated piperazine at the CSIRO designed and built Tarong pilot plant (100 kg CO_2 / hour) lo-

2. *A. Cottrell, et al., Performance of CSIRO Absorbent Liquid 008 (CAL008): Parametric Study and 5,000 Campaign. 14th Greenhouse Gas Control Technologies Conference Melbourne 21-26 October 2018 (GHGT-14). DOI: dx.doi.org/10.2139/ssrn.3365610*

cated at Stanwell's black coal Tarong Power station in Queensland[3].

• Campaigns using aqueous ammonia and advanced process designs to mitigate ammonia loss and allow co-capture of sulphur dioxide at a CSIRO designed and built pilot plant (300 kg CO2 / hour) located at Delta Electricity's black coal Vales Point Power Station in New South Wales[4].

• Campaigns using an advanced amine based process configuration (CS-Cap) that allows the separated but integrated capture of sulphur dioxide and carbon dioxide in a single absorber column at a CSIRO designed and build pilot plant (50 kg CO2 / hour) located at AGL's brown coal Loy Yang Power Station in Victoria[5].

Looking to the future

Closing the carbon cycle with direct air capture (DAC) and utilisation

Using the successful development of amine-based post-combustion capture technologies as a template the team is now addressing the challenging field of direct air capture[6]. The low concentrations of CO2 in air require much larger gas-liquid contactors and more energy intensive regeneration processes than more concentrated point sources.

Our initial techno-economic analysis has revealed that there is potential to reduce the direct air capture costs to levels below $100 / tonne CO2 through the use of cheaper equipment materials, process and equipment innovation and modular scale-up. Cost-effective direct air capture processes have considerable potential to contribute to the realisation of negative emissions and net zero emission fuels and can be readily added to existing CCUS hubs. In combination with utilisation, DAC closes the carbon cycle.

Recent work in this area has focused on the design and characterisation of low cost gas-liquid contactors able to operate at the large ratio of gas to liquid flow necessary for direct air capture and robust and environmentally benign absorbents. One example of this using a contactor based on a standard air conditioning cooling tower and an amino-acid based absorbent is shown on the back cover.

The next steps involve an integrated absorption and desorption demonstrator able to run wholly on renewable energy. Other fundamental work is focused on how the absorbed CO2 can be delivered to electrochemical and thermochemical CO2 utilisation processes for the production of fuels (e.g. syngas, methane and methanol) and carbonate containing building materials in an integrated way that eliminates the energy intensive regeneration of absorption liquids.

Figure 4 - The PICA (PCC IHI CSIRO AGL) carbon capture pilot plant located at the AGL Loy Yang Power Station, Victoria, Australia

Heavy industry and other hard-to abate emissions

Similar to the case of direct air capture, the team is also now addressing the challenging field of carbon capture from heavy industry. The main component of CSIRO's CAL absorbent technology that has been demonstrated at scale for 5,000 hours is now included as a proprietary component in the ProTreat® processing modelling package from Optimized Gas Treating, Inc.

This provides a platform for absorbent formulation, process design, simulation and optimisation that the team is undertaking for emissions from industrial gas streams such as those from cement manufacturing, aluminium smelting and biogas upgrading.

We at CSIRO Energy see carbon capture technologies having numerous roles in mitigating CO2 emissions to the deep levels needed to meet current and future global emissions targets. Even as energy systems move away from fossil fuels to renewables and other low carbon emission energy generation, some will remain along with heavy industries requiring carbon capture.

Additionally, the development of direct air capture technologies to remove emitted CO2 from the atmosphere looks increasingly necessary to provide an insurance policy for the future against the still intensive emissions occurring now. Moreover, when combined with renewable hydrogen generation it provides a pathway to net zero emission liquid fuels.

More information

www.csiro.au/energy

3. *A. Cousins, et al., Model verification and evaluation of the rich-split process modification at an Australian-based post combustion CO2 capture pilot plant. Greenhouse Gases Science and Technology, 2 (2012), 329-425. DOI: doi.org/10.1002/ghg.1295. 2. A. Cousins, et al., Pilot-scale evaluation of concentrated piperazine for CO2 capture at an Australian coal-fired power station: duration experiments. Greenhouse Gases Science and Technology, 5 (2015), 363-373. DOI: doi.org/10.1002/ghg.1507.*

4. *H. Yu, et al., Development of an advanced, aqueous ammonia-based CO2 capture technology: Pilot plant demonstration and techno-economic assessment. 15th Greenhouse Gas Control Technologies Conference Melbourne 15-18 March 2021 (GHGT-15). Available at SSRN: https://ssrn.com/abstract=3811344.*

5. *P. Pearson, et al., An update on the development of the CSIRO's CS-Cap combined CO2 and SO2 capture process. Energy Procedia, 114 (2017), 1721-1728. DOI: doi.org/10.1016/j.egypro.2017.03.1301.*

6. *The research is driven by the needs for technology improvement, resulting from detailed techno-economic analysis of the amine-based DAC process as described in A. Kiani, et al., Techno-Economic Assessment for CO2 Capture from Air Using a Conventional Liquid-Based Absorption Process. Frontiers in Energy Research, 8:92 (2020). DOI: 10.3389/fenrg.2020.00092.*

Technical competence

MAN PrimeServ

Service with passion

We at MAN PrimeServ understand that performance and reliability are paramount to your business. You need technical competence that drives your success. MAN PrimeServ's many decades of hands-on experience and its diverse portfolio provide this. With MAN PrimeServ as your partner you benefit from state-of-the-art technical and digital solutions that fit your individual situation. What's more, these benefits are brought directly to your business through a global network of local experts. Whatever the time and wherever you are in the world, you can count on MAN PrimeServ as a strong service solution provider for your needs.

To find out more about our technical competence, please visit:

www.man-es.com

MAN

Australia proposes inclusion of CCS in Carbon Credits Market

The proposed method will enable CCS projects which capture and permanently store greenhouse gases underground to generate Australian carbon credit units (ACCUs).

The Australian Government's first Low Emissions Technology Statement – 2020 identified carbon capture and storage as one of Australia's priority low emissions technologies.

In late 2020, the Minister for Energy and Emissions Reduction tasked the Clean Energy Regulator with developing a CCS method under the Emissions Reduction Fund.

A CCS project captures greenhouse gas emissions that would otherwise have been released to the atmosphere. It transports them for injection into an underground geological formation for permanent storage.

The technology can underpin new low emissions industries such as hydrogen. It can also reduce emissions in hard to abate sectors such as cement production and steel manufacture.

Why the consultation

The Emissions Reduction Assurance Committee is seeking feedback on a proposed new methodology determination under the Emissions Reduction Fund:

• Carbon Credits (Carbon Farming Initiative—Carbon Capture and Storage) Methodology Determination 2021

The proposed method would enable projects that capture and permanently store greenhouse gases in underground geological formations to generate Australian carbon credit units.

The Minister for Energy and Emissions Reduction is required to consider a range of factors when deciding whether to make a new method. This includes whether an activity under a method could have any adverse social, environmental, or economic impacts.

As such, feedback may cover adverse impacts that are likely to arise from carrying out a CCS project under the proposed new method. Information on the operation of the proposed CCS method is in the draft CCS Simple Method.

Submissions can be made until the 27th of July through the Department of Industry, Science, Energy and Resources consultation hub

About the Emissions Reduction Fund

The Emissions Reduction Fund is a voluntary scheme that aims to provide incentives for a range of organisations and individuals to adopt new practices and technologies to reduce their emissions.

A number of activities are eligible under the scheme and participants can earn Australian carbon credit units (ACCUs) for emissions reductions. One ACCU is earned for each tonne of carbon dioxide equivalent (tCO2-e) stored or avoided by a project.

ACCUs can be sold to generate income, either to the government through a carbon abatement contract, or in the secondary market. Various eligibility criteria must be met to qualify for the fund.

To ensure these emissions reductions are not displaced significantly by a rise in emissions elsewhere in the economy, the Emissions Reduction Fund also includes a safeguard mechanism, which encourages large businesses to keep their emissions within historical levels.

There are four steps to participating in the Emissions Reduction Fund:

• Join the scheme by registering yourself and your project.

• Secure a contract with the Australian Government by participating in an auction. auctions.

• Run your project according to the method you have chosen to use. Report on your project and ensure it is audited when required.

• Claim Australian carbon credit units (ACCUs) for the emissions reductions you have achieved and sell them.

The safeguard mechanism

The Emissions Reduction Fund has three key elements, including crediting, purchasing and safeguarding emissions reductions.

The safeguard mechanism complements the emissions reduction elements of the Emissions Reduction Fund by sending a signal to businesses to avoid increases in emissions beyond business-as-usual levels.

It achieves this by placing a legislated obligation on Australia's largest greenhouse gas emitters to keep net emissions below their emissions limit (or baseline).

The safeguard mechanism operates under the framework of the National Greenhouse and Energy Reporting scheme and applies to facilities with direct scope 1 emissions of more than 100,000 tonnes of carbon dioxide equivalent (t CO2-e) per year.

This extends to businesses across a broad range of industry sectors, including electricity generation, mining, oil and gas, manufacturing, transport, construction and waste. Collectively, these facilities account for about half of Australia's emissions.

Safeguard facilities will be able to surrender Australian carbon credit units (ACCUs) to offset emissions over their baseline.

More information

www.cleanenergyregulator.gov.au
consult.industry.gov.au

Australia invests $50 million in carbon capture projects

Six carbon capture projects have received funding to accelerate the development of the technology in Australia, sharing $50 million from the Carbon Capture, Use and Storage Development Fund.

The projects demonstrate several ways that carbon capture technology can reduce emissions from hard-to-abate sectors.

The successful applicants are:

• Santos Limited – up to $15 million towards the low-cost capture and storage of CO2 emitted from Santos's Moomba LNG operations for permanent storage in the Cooper Basin, South Australia. The project is expected to store 1.7 million tonnes per annum on an ongoing basis.

The project will achieve the Fund's objectives by reducing emissions in the natural gas sector and establishing facilities that could, in the future, bring together a network of greenhouse gas emitters enabling reductions in costs and risks for CCS projects and large-scale abatement.

Santos' Moomba LNG project will be one of the lowest-cost CCS projects in the world at A$25-30 per tonne of CO2 (Image: Santos)

Santos Chief Executive Officer and Managing Director Kevin Gallagher said the project will also be one of the lowest-cost projects in the world at A$25-30 per tonne, driving towards the Australian Government's stretch goal to compress, transport and store CO2 for less than A$20 per tonne.

• Mineral Carbonation International – up to $14.6 million towards the construction of a mobile demonstration plant that captures and uses CO2 to produce manufacturing and construction materials, such as concrete, plasterboard and fire-retardant materials on Kooragang Island, New South Wales.

• Energy Developments Pty Ltd – up to $9 million towards the capture and use of CO2 emitted from the production of biomethane at landfill sites across multiple locations across Australia for use in cement carbonation curing.

• Carbon Transport and Storage Company – up to $5 million to demonstrate the viability of carbon capture and storage from a coal-fired power station in Queensland and support the development of a geological storage basin in the Surat Basin.

• Corporate Carbon Advisory Pty Ltd – up to $4 million towards Australia's first demonstration of a direct-air-capture (DAC) and storage project to geologically sequester CO2 in an existing injection well in Moomba, South Australia.

• Boral Limited – up to $2.4 million towards a pilot scale carbon capture and use project to improve the quality of recycled concrete, masonry and steel slag aggregates at New Berrima, New South Wales.

Minister for Energy and Emissions Reduction Angus Taylor said the overwhelming demand for funding through the CCUS Development Fund was further proof of the viability and importance of carbon capture technologies.

"We received funding applications to support $1.2 billion of investment in carbon capture projects and technologies," Minister Taylor said.

"The projects we have supported through this program include a number of exciting, Australian-first technology demonstrations."

The CCUS Development Fund is part of the Government's $1.9 billion new energy technologies package announced in the 2020-21 Budget. The $1.9 billion package included resourcing to support the development of a CCS method for the Emissions Reduction Fund (ERF), which is expected to be completed later this year.

Further funding opportunities are available through the $263.7 million announced in the 2021-22 Budget for CCUS projects, hubs and technologies and the Australian Renewable Energy Agency (ARENA).

The Government said it is committed to supporting the commercial deployment of CCUS and its uptake.

More information

business.gov.au

Santos chief executive Kevin Gallagher calls on Australia to be 'CCS superpower'

In a speech to the 2021 APPEA Conference he said Australia can become a carbon storage superpower based on its vast tracts of pastoral and cropping land and depleted oil and gas reservoirs.

Decarbonisation is a new industry opportunity for Australia, he said, through carbon capture and storage, biological sequestration in soil and vegetation, and development of a new hydrogen industry.

Just as Japan and Korea have counted on Australia to supply the energy resources to feed their economies over the last half century, they and other countries can look to Australia to help meet their emissions reduction targets.

This is because they don't have the land we have for biological carbon sequestration or the geology for carbon capture and storage, known as CCS.

Australia has vast tracts of land on which it can store carbon from the atmosphere through soil and vegetation – a fantastic opportunity for our farmers and pastoralists.

And Australia has a natural competitive advantage in CCS with known highquality, stable geological storage basins capable of injection at a rate of 300 million tonnes per annum for at least 100 years. These are the same basins that have safely and permanently held oil and gas in place for tens of millions of years.

They are the same basins where many APPEA members have already demonstrated their ability to inject gases because we are already doing it to enhance oil production or to store gas so it can be brought to market quickly in periods of high demand.

This is proven technology with Australia already hosting the world's largest CCS project – the Gorgon Carbon Dioxide Injection Project at Barrow Island right here in Western Australia.

Later this year Santos will take a final investment decision on one of the world's largest CCS projects, after the Clean Energy Regulator's methodology for CCS to generate Australian Carbon Credit Units is in place.

New technologies like direct air capture – extracting carbon dioxide directly from the atmosphere – will potentially allow us to continue to utilise our vast carbon storage potential without having to capture emissions from hard-toabate industry sectors.

Today the world stores about 40 million tonnes of carbon dioxide per year through CCS, but the International Energy Agency's 2020 report on CCS says we will need to store 5.6 billion tonnes per year by 2050 to meet our climate goals – more than a hundredfold increase on today's levels.

CCS could not only reduce Australia's emissions. It can protect existing domestic and export industries by creating offset opportunities for industries from airlines to manufacturing, preventing the lossof tens of thousands of well-paid jobs across the country.

It could also open up a new export industry for Australia – building on our existing trade and investment in LNG with future trade and investment in carbon credits and clean fuels such as hydrogen and carbon-neutral LNG.

Australia has a further global competitive advantage through its wellestablished National Greenhouse and Energy Reporting Scheme, Emissions Reduction Fund and Clean Energy Regulator.

These regulatory frameworks and institutions underpin an unsurpassed reputation for carbon accounting integrity and quality of carbon credits.

The price of Australian Carbon Credit Units is now around A$19 per tonne of carbon, but the price of carbon in Europe recently hit A$90 per tonne.

The ability to sell Australian Carbon Credit Units to trading partners such as Japan and Korea could incentivise more CCS and biological sequestration projects to be developed right here in Australia.

But this would require the negotiation of bilateral agreements with prospective buyers such as Japan and Korea, and regulatory frameworks for carbon accounting across international borders, that are not yet fully in place.

Australia needs large-scale CCS projects to make development of our oil and gas resources viable for investors, financiers and customers so that the wealth of these resources can be unlocked for the nation.

Converting gas into hydrogen also offers the fastest, lowest-cost pathway to a hydrogen economy and, combined with CCS, could put Australia at the forefront of this new industry while the technology for renewable hydrogen evolves and the costs come down.

Summing up, to suggestions that Australia can become a clean energy superpower I would add this observation.

Australia can become a carbon storage superpower based on our vast tracts of pastoral and cropping land, and our depleted oil and gas reservoirs.

At this year's APPEA conference, I urge everyone to therefore consider decarbonisation not simplistically as a threat – but as an opportunity to establish a new, large-scale industry producing carbon offsets that will be inheavy demand from emitting countries that lack Australia's competitive advantages in carbon storage.

The Australian Petroleum Production and Exploration Association is the national body representing Australia's upstream oil and gas sector.

More information

www.appea.com.au

www.santos.com

With more than 90 active patents for carbon capture, Babcock & Wilcox has been a leader in the research and development of decarbonization technologies for more than four decades.

Our ClimateBright™ technologies generate needed power, while lowering greenhouse gases and other emissions, to contribute toward the ambitious but important goal of a carbon net-zero world.

Together, we can and we must

CO_2llaborate 2 Decarbonize

B&W BABCOCK & WILCOX

Learn more about B&W's ClimateBright™ technologies at: https://babcock-decarbonization.com/

The future of CCUS: the route to net zero

Mitsubishi has been at the forefront of solving the carbon capture challenge, supporting 13 commercial carbon capture plants globally. By Makoto Susaki, Senior Vice President and CTO, Mitsubishi Heavy Industries Engineering and Head of CCUS Business Taskforce, Mitsubishi Heavy Industries.

Lowering our carbon output is the only way we will be able to meet the Paris Agreement goal of keeping global warming below 1.5 degrees Celsius.

Annual worldwide CO_2 emissions must be reduced by more than 80%, from the current 40 gigatons, if carbon neutrality is to be achieved by 2050.

And while we have seen significant growth of carbon free renewable energy sources, they will not single-handedly get us to net zero.

Increasingly, carbon capture, utilization and storage (CCUS) is playing a critical role in decarbonizing our energy system.

The International Energy Agency (IEA) has recognized CCUS as a key pillar in the clean energy transition, observing that it is the only solution capable of both reducing and removing emissions.

However, unlike with renewable energy, policy development around carbon capture has been far from clear-cut.

Mitsubishi Heavy Industries Engineering recently agreed a long-term contract for Drax to use its carbon capture technology, the Advanced KM CDR process™. Pictured L-R: Kentaro Hosomi, Chief Regional Officer EMEA, Mitsubishi Heavy Industries (MHI); Carl Clayton, Head of BECCS, Drax Group; Jenny Blyth, Project Analyst, Drax Group at Drax Power Station, North Yorkshire

To decarbonize areas of the economy that cannot easily be electrified, there must be a coordinated effort to rapidly deploy both the carbon capture and storage (CCS) and carbon capture and utilization (CCU) markets.

The goal of these efforts has to be directed towards creating an end-to-end value chain for CO2 that can advance its commercial viability.

More than just a value chain, there is potential for this end-to-end approach to become a holistic carbon ecosystem that includes carbon capture, transportation, storage and utilization. Eventually, the enhanced recycling of CO2 could transform it into a valuable commodity.

Cleaning up energy

Today, carbon capture is in use across a range of industries globally, including the energy sector, where it is set to produce significant results.

Even now, carbon capture technologies can remove more than 90% of the carbon dioxide emissions generated by fossil-fueled power stations and other industrial plants.

MHI Engineering (MHIENG), part of Mitsubishi Heavy Industries (MHI) Group, has historically been involved in the carbon capture piece of the puzzle, and so far supported 13 commercial carbon capture plants globally, with a total capacity equivalent of capturing three million metric tons a year, including the world's largest CO2 capture plant delivered to Petra Nova Parish Holdings LLC, U.S. in 2016.

The company has recently seen an increase in interest from a growing number of industries and has responded in kind.

In the energy sector, in a world-first for the liquefied natural gas (LNG) industry, MHI is participating in the roll-out of a large-scale post-combustion carbon capture facility at the Rio Grande LNG project in Texas. NextDecade expects to capture and permanently store more than five million metric tons of CO_2 per year.

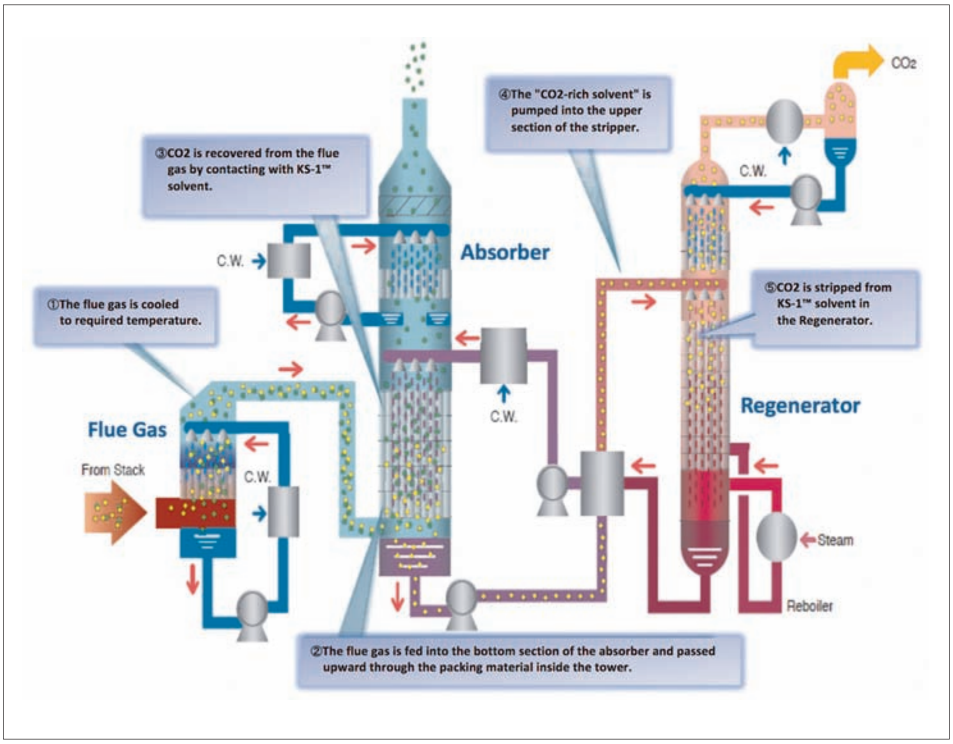
Like all of the carbon capture plants MHIENG has worked on, the Rio Grande facility will use the Kansai-Mitsubishi Carbon Dioxide Removal Process (KM CDR ProcessTM), a post-combustion carbon capture technology developed by MHIENG together with Kansai Electric Power, one of the major utility company in Japan.

In an effort to make this process ever-more efficient, MHIENG has developed a new proprietary solvent for capturing CO2, which has been shown to have lower volatility, greater stability against degradation, less environmental impact and reduced running costs compared to earlier versions. The solvent is currently being tested at Technology Centre Mongstad in Norway, to demonstrate at industrial scale these advantages.

The success of the test program is helping to drive an expansion of MHIENG's carbon capture operations in Europe, including the development of a Bioenergy with Carbon Capture and Storage (BECCS) facility at the Drax Power Station in the UK.

BECCS applies CCS to power plants that generate reliable baseload power and heat from renewable resources like biomass. MHIENG is working with Drax to deploy the technology at the generator's site in the north of England, in what could become the largest delivery of negative emissions anywhere in the world.

Drax is already carrying out the largest decarbonization project in Europe, having converted its power station to use sustainable biomass instead of coal and reducing its emissions by 85%. With BECCS technology, Drax aims to go even further, becoming carbon negative by 2030.



Graphic showing Mitsubishi Heavy Industries (MHI) carbon capture technology process

Once BECCS is scaled up, Drax expects to capture and permanently store at least eight million metric tons of CO2 a year – a significant proportion of the negative emissions the Climate Change Committee says are needed in order for the UK to reach its climate targets.

Capturing shipping emissions

The shipping industry carries over 80% of global trade and is taking steps to reduce its emissions, aiming to halve CO_2 emissions by 2050. This is another area of the global economy that could benefit from deploying carbon capture and putting CO_2 to good use.

MHI Group is developing a carbon capture unit for maritime use, where carbon will be removed from marine exhaust gases. Working with Kawasaki Kisen Kaisha ("K" Line) and Nippon Kaiji Kyokai (ClassNK), Mitsubishi Shipbuilding will conduct a demonstration test, installing a CO2 capture system on board a ship in active service. If successful, the Carbon Capture on the Ocean project would represent a world first in capturing CO2 at sea.

Fixing concrete

The area in which CCS shows the most promise in helping to reach net-zero emissions is in decarbonizing heavy industries.

Industries like steel and chemical manufacturing rely heavily on fossil fuel-generated industrial heat, or use coal and gas as feedstocks. Some could potentially move to hydrogen. For others, such as the cement industry, carbon capture may be the only route to significant emissions cuts.

Many hope that socio-economic recovery from the impact of the COVID-19 pandemic will lead to growth in sustainable infrastructure development. However, concrete, a key building material, is also a heavy polluter. Cement, one of its primary ingredients, is responsible for 8% of global CO2 emissions.

Finding viable, low-carbon alternatives could make a huge difference when it comes to building more sustainably.

MHI Engineering is taking part in a feasibility study to utilize CCS in cement production at the Lehigh Cement Plant in Edmonton, Canada. This will be one of the first such studies in the North American market and is estimated to capture about 600,000 metric tons of CO2 annually.

Converting a well-known greenhouse gas into a valuable commodity

Not only can CCS take carbon out of the emissions generated by cement production, but it can also be put to work afterwards. For example, it can be injected into concrete to reinforce it, while also creating a long-term CO_2 repository.

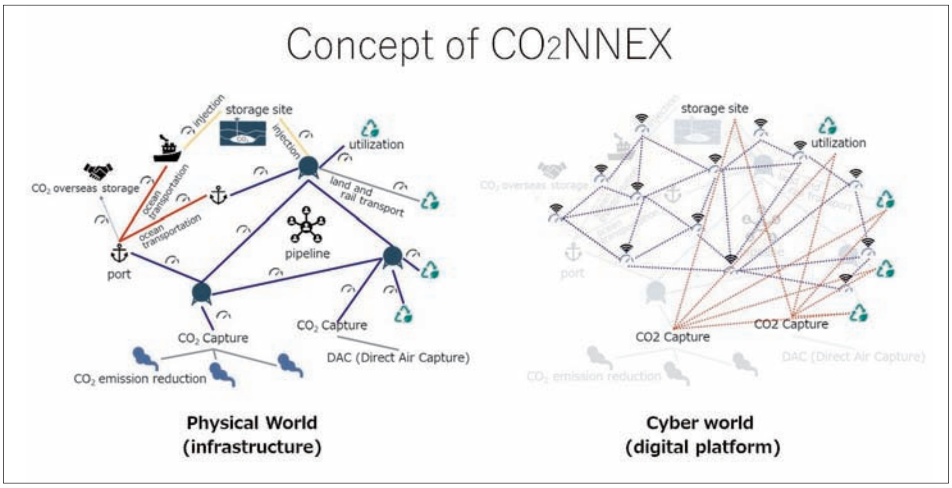
Researchers at the University of California, Los Angeles (UCLA) have developed a closed-loop process that involves capturing carbon from power plant smokestacks and using it to create a new building material.

Scaling up the use of such materials will enable a sea-change in construction activity, according to a report from the Chatham House think tank, which notes that novel types of cement alone could allow emissions reductions of up to 90% in the building sector.

Captured carbon can also be used to develop alternative fuels that are more sustainable than fossil fuel-based products.

MHI has recently invested in Infinium, alongside other major global organizations including Amazon. Infinium's technology enables the production of ElectrofuelsTM by converting carbon dioxide and renewable power into net-zero carbon fuels. These clean fuels allow organizations to meet carbon reduction goals faster while accelerating the transition away from fossil fuels. ElectrofuelsTM can be used in air, maritime and surface transportation fleets.

Although carbon dioxide is commonly seen as having a negative impact, it clearly can have multiple positive uses as a resource. Globally, over 36 billion metric tons of CO2 are emitted every year. Capturing and converting those emissions into products that benefit the economy and the environment will bring us closer to our decarbonization goals.



Connecting the dots

In the long term, the success of CCUS depends on the physical and digital networks that are established between the emitters of CO2 – like power plants and factories – and the transport, storage and use of it, for example as a fuel in shipping or the production of cement. This network would be invaluable in widening both the capture and potential use and storage of CO2.

Affordable transportation of CO2, by ship or pipeline, will be key to ensuring the future connectivity of the supply chain.

MHI is studying the feasibility of a liquified CO2 (LCO2) carrier that could transport large amounts of LCO2 safely over long distances and at a low cost. Such a carrier would be the cornerstone in the carbon transportation network and could play a vital role in a decarbonized society.

Digitally, through the CO2NNEX™ initiative, MHI and IBM Japan are working to visualize and strengthen the CO2 supply chain. Linking and visualizing how CO2 moves through the supply chain and providing traceability will make it easier to optimize and expand the CCUS network, and help provide more pricing certainty for investors.

The system could also expand the scope of CO2 utilization by matching CO2 emitters with companies who are able to use it or store it, providing supply for new applications in sectors such as industry, agriculture and alternative e-fuels.

Multi-stakeholder partnerships like these, alongside government support, can create a stronger opportunity to benefit the environment by accelerating the development of further decarbonization tools, such as direct air capture technology.

Opportunity knocks but a joint effort needed

Although it is still in its early stages, carbon capture could potentially sequester a third of all industrial emissions by 2040. But to realize this opportunity, policymakers, investors and the energy sector need to develop a framework for containing, connecting and converting CO_2 for the technology to scale up and take off.

Today, there are fewer than 30 commercial CCUS plants operational worldwide, but more than 60 at the development stage.

The number of operational CCUS facilities will need to scale up rapidly to meet ambitions to reach global net zero CO2 emissions, according to the IEA. It says the world will need to capture nearly 200 times the amount of CO2 it does today: from 40 million metric tons of CO2 captured in 2020 to 7,600 million metric tons per year in 2050.

Governments and industry need to work together to rapidly deploy both the carbon capture and storage (CCS) and carbon capture and utilization (CCU) markets. Governments can support the deployment of carbon capture through stimulus packages that provide direct support and stimulate investment in technology development. This could take the shape of positive incentives such as direct capital grants, tax credits, operational subsidies and risk-sharing in projects – or disincentives like carbon pricing mechanisms.

Alongside this, governments need to drive the development of industrial hubs with shared CO2 infrastructure. One example of this is the North Sea CCU Hub at North Sea Port, an area stretching along the Belgian and Dutch coastlines. Alongside capturing carbon from participating companies, the hub will also synthesize chemicals and fuels such as methanol.

Similarly, at the Zero Carbon Humber site in the north of England, CO2 from industrial sources will be transported via pipelines and stored beneath the North Sea, giving energy-intensive sectors the opportunity to reduce their carbon footprint and the ability to switch to low-carbon hydrogen as a fuel source.

And while the IEA considers global CO2 storage resources sufficient to meet and exceed future demand, the onus will be on governments to identify and support CO2 storage in strategic locations, including a strong regulatory framework for storage and transport.

The need for funding innovation remains a priority. The IEA estimates that almost two-thirds of the cumulative emissions reductions required by 2070 depend on technologies that currently are at the prototype stage or, at best, in the demonstration phase.

But these priorities for national policymakers are not ones they should tackle in isolation. Enabling the rapid commercial deployment of proven CCS technology in the market will take a joint effort from policymakers, investors and industry across the world. The heavy lifting needed to make this a reality must become an international priority – and urgently.

More information

spectra.mhi.com

www.drax.com

Increasing hydrogen storage effectiveness on the path to net zero

Hydrogen has great potential to help society decarbonise across different sectors, however there are technical and operational challenges that should not be underestimated. By Edris Joonaki, Fluid Properties Expert at TÜV SÜD National Engineering Laboratory.

In the global fight against climate change, many nations are already committed to reducing energy consumption and have set ambitious goals to minimise carbon emissions. This includes the Paris Agreement (COP21), the Renewable Energy Directive (RED I, RED II) and the European Green Deal. To achieve net zero targets by 2050, there must be significant decarbonisation and a substantial change will be required in the way energy is generated, stored, transported and consumed.

To achieve this, the emissions from fossil fuels must be reduced and the energy mix transition to low carbon energy sources must be accelerated. Hydrogen has great potential to help society with decarbonisation across different sectors including transportation, heat and power. Hydrogen can support this transition by:

• Replacing natural gas for domestic and industrial uses

• Replacing coal and natural gas for power generation

• Replacing fuel oil and gasoline to decarbonise transport

• Facilitating greater use of renewable energy by acting as an energy carrier to balance supply and demand.

Gigawatt-scale geological storage will be required to enable hydrogen as a low carbon energy pathway. Proven technologies that could provide the necessary scale for hydrogen storage include underground salt caverns, depleted oil and gas reservoirs and deep salined aquifers.

This isn't a new technology; hydrogen-rich town gas mixtures have been stored in geological formations since the 1970's and currently, over 1,000,000 m3 of hydrogen is stored in underground salt caverns.

Successful storage

The storage of gas in the subsurface reservoirs as geological energy storage, whether as natural gas or hydrogen (the working gas), requires a cushion gas to prevent brine from entering the production stream and to maintain the required reservoir pressure ensuring deliverability.

As depleted gas fields are being considered as subsurface storage sites for hydrogen, the in-situ gas could be used as the cushion gas and hence the working and cushion gasses will be of different compositions. For gas storage in saline aquifers, where there is very little in-situ gas present, there is a requirement to use a cushion gas that is significantly less expensive than the working gas. Options for aquifer storage cushion gasses include nitrogen, due to its low price, and CO2 due to its high compressibility and potential for secure storage.

During the injection/production cycles, mixing of the gas components is inevitable and is determined by parameters such as mobility ratios, density differences, molecular diffusion and mechanical dispersion. The numerical simulation of any storage scenario must confirm that the working gas can be produced with minimal cushion gas contamination.

Therefore, if the cushion gas and working gas are of different compositions, the accurate quantification of the cushion gas/working gas mixing zone is of paramount importance. Once mixing takes place, the different gaseous components will alter the properties of the gas and introduce significant uncertainty into the expected behaviour of the injected, stored and produced gas.

For gas storage modelling, accurate thermodynamic reference data for relevant fluid mixtures, which can either be directly imported into reactive fluid flow modelling software or can be used to confirm existing reservoir simulation software outputs, is an important tool to enhance the compliance for scenario modelling results.

Understanding hydrogen streams

It is clear that as hydrogen is vital to our future energy system, an in-depth understanding of the properties of hydrogen-containing streams is crucial. To facilitate this, we must understand the thermodynamic properties of hydrogen-containing systems, as the thermodynamic properties of hydrogen gas mixtures under a variety of pressure and temperature operating conditions can be employed to design and optimise hydrogen production units, transportation, and storage processes.

To determine the properties of hydrogen-rich mixtures, we need to have knowledge of the stream composition as well as the temperature and pressure conditions of the stream, as all these data are employed as inputs of thermodynamic models.

Almost 96 % of hydrogen is currently blue hydrogen, produced through endothermic methane reforming. For every ~1 kg of blue hydrogen produced, ~7 kg of CO2 is also produced as a by-product. Carbon capture and storage (CCS) technology is therefore vital, following the methane or natural gas reformation process.

In CCS systems the methane, natural gas and CO2 may be mixed with hydrogen at various molar fractions. Thermodynamic data such as Vapour Liquid Equilibria diagrams, viscosity, density, thermal conductivity and thermal capacity data for hydrogen-containing streams can provide scientists withe a fundamental understanding of reactive fluid flow through geological porous media for hydrogen storage purposes.

It can also be utilised for precise flow measurement of hydrogen-rich systems.

GERG-2008 Equation of State (EoS) + **SuperTRAPP Model** = **Thermophysical properties**

Dimensionless Helmholtz energy:

$\alpha(\delta,\tau,x) = \alpha^{o}(\rho,T,x) + \alpha^{r}(\delta,\tau,x)$

$\tau = T/T_r$ $\delta = \rho/\rho_r$ x is the molar composition

$\mu(T,\rho) = \mu^{*}(T) + \Delta\mu_0(T_0,\rho_0)F_{\mu}(T,\rho)$

* refers to dilute gas and 0 refers to a reference fluid

Ideal-gas contribution:

$\alpha^{o}(\rho,T,x) = \sum_{i=1}^{N} x_i[\alpha^{o}_{oi}(\rho,T) + \ln x_i]$

N: Number of mixture components

x_i: The mole fraction of each component i

The residual part of Helmholtz energy:

$\alpha^{r}(\delta,\tau,x) = \Sigma_{i=1}^{N}\, x_i\, \alpha^{r}_{oi}(\delta,\tau) + \Delta\alpha^{r}(\delta,\tau,x)$

$\Delta\alpha^{r}$: Departure function

Figure 1 - Description of Thermodynamic Model

Thermodynamic properties of hydrogen mixtures

In a recent study, TÜV SÜD National Engineering Laboratory employed the established and well regarded GERG-2008 Equation of State (EoS) integrated with SuperTRAPP model to predict phase behaviour, density, and viscosity of gas mixtures related to the hydrogen transportation and storage processes covering the thermodynamic properties of gas/liquid/supercritical regions.

In the GERG EoS, the dimensionless Helmholtz Energy is used. This is a function of inverse reduced temperature, reduced density, and molar composition of the gas mixture and consists of two parts. The first part is for ideal gas contribution as you can see in Figure 1; a function of the number of mixture components and the mole fraction of each component in the system.

The second part is the residual part of Helmholtz energy which is a function of the dimensionless Helmholtz energy of component i in the ideal-gas phase, and the departure function that is a function of density, temperature and composition. The viscosity of the system can be determined using the SuperTRAAP model that consists of a dilute-gas and residual contribution and is a function of density and temperature.

The densities predicted using GERG-EoS for different 50% H2 mixtures containing methane, CO2 and a typical north-sea natural gas suggest that density is influenced more by the presence of CO2 than methane or natural gas. This is due to the fact that the density of CO2 is greater than methane and natural gas.

The densities of the streams increment with increasing pressure for all isotherms based on Boyle's Law and decrease with increasing temperature based on Charles's Law. On the other hand, the density values of mixtures in the presence of higher concentrations of H2 are smaller compared to the low hydrogen concentration systems.

The estimated viscosity values for different H2 mixtures with methane, CO2 and natural gas over a wide range of pressures and temperatures using integrated GERG-2008 EoS and the SuperTRAPP model, show that the viscosity of the mixtures increases with augmentation of both pressure and temperature.

This can be attributed to the fact that an increase in pressure or temperature increases the velocities of the random motion of molecules and the occurrence of molecular collisions that resist the flow of gas and increase the viscosity. Conversely, the viscosities of the mixtures are reduced with increasing H2 mole fractions in the system as H2 has a significantly lower viscosity compared to other gases owing to its smaller molecule size.

As highlighted previously, blue hydrogen production via methane/natural gas reforming is an endothermic process and requires massive heat supply to be fully operational. Moreover, when hydrogen is injected into a depleted hydrocarbon reservoir for storage, it is mixed with methane and potentially has a reactive fluid transport in porous reservoir rock owing to the geochemical reactions with rock surfaces at high temperature and pressure conditions in that environment.

It is therefore crucial to determine the thermal conductivity and thermal capacity of hydrogen and methane mixtures. The estimated isobaric heat capacities for H2/methane mixtures using GERG-2008 EoS have higher values in the presence of a higher concentration of hydrogen. This occurs as a result of the heat capacity of pure hydrogen being higher than that of pure methane at temperatures and pressures above the critical point of methane. It should be highlighted that with pressure increment, the thermal capacities increase for all temperature conditions due to increased intermolecular forces.

Our research has shown that as the temperatures and pressures are close to the critical conditions of methane, peaks emerged. The estimated thermal conductivities for H2/CH4 blends, again under various pressures and temperatures utilising combined GERG-2008 EoS and the SuperTRAPP model, denote that the thermal conductivity values increase with increasing pressure for all isotherms. These behaviours can be attributed increased molecular motion at higher pressures and temperatures, improving the conduction of heat within gas molecules.

Generally, it should be noted that thermal conductivity values increase with increasing hydrogen concentration in the system, as pure hydrogen has a remarkably higher thermal conductivity than methane. The vapour-liquid phase envelopes for the hydrogen-natural gas, hydrogen-methane, and hydrogen-CO2 blends with different mole fractions of hydrogen present are detailed in Figure 2.

As can be observed, some parts of the two-phase region of the H2 + CO2 and the H2 + natural gas streams are within the pressure and temperature ranges of geological storage sites and transportation pipelines.

These two-phase liquid-gas regions of the stream impact on flow measurement in several ways, that's why recognition of these regions is crucial. If the dominating phase changes from that for which the meter is intended, the precision of the flow meter will be considerably impacted to the point where fiscal measurements are not feasible.

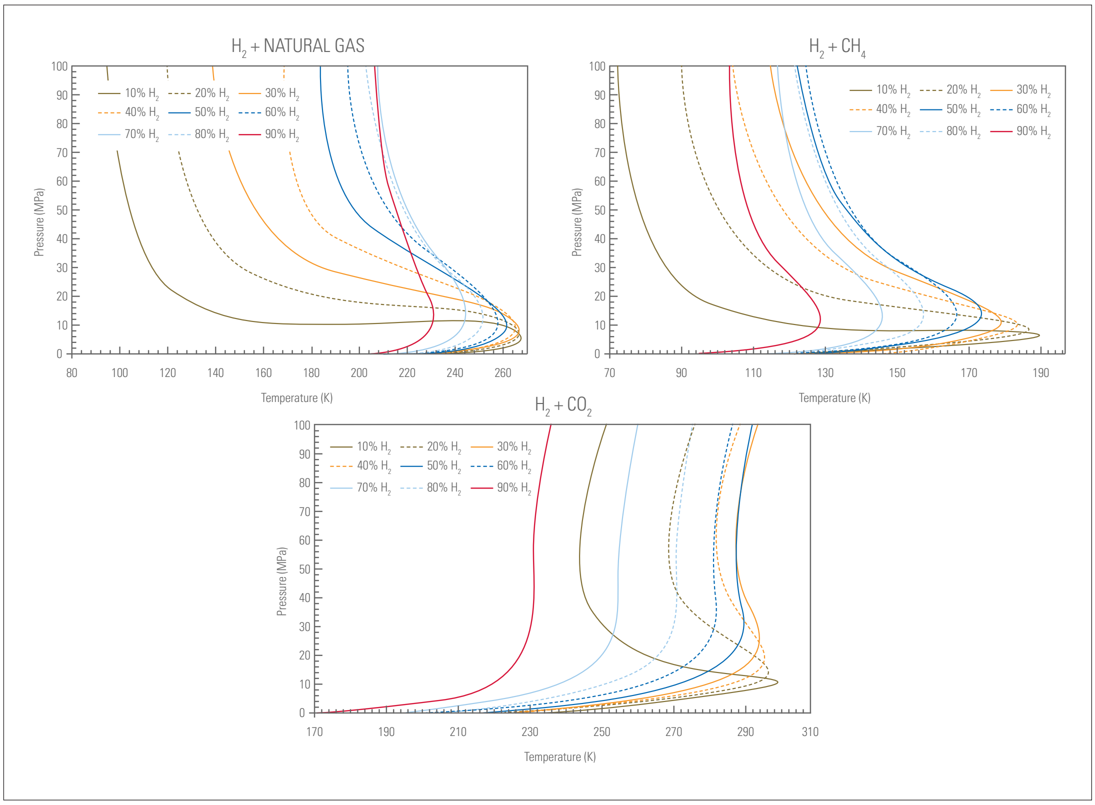


Figure 2 - Predicted Vapour Liquid Equilibria (VLE) diagrams using adequate thermodynamic models for different H2 containing mixtures with various H2 mole fractions over a wide range of pressures and temperatures.

Future challenges

Thermodynamic data for hydrogen-containing systems can enable scientists to have a deeper understanding of reactive flow through porous media during hydrogen storage processes. Our research has shown that the thermodynamic properties of hydrogen when mixed with other gaseous species including CH4, CO2 and natural gas can be determined using adequate thermodynamic models.

These models could be successfully applied to various pressure and temperature operating conditions and gas mixture components which cover the conditions experienced within the whole hydrogen-based energy system, from production to storage in geological formations.

Another target in a hydrogen-based economy is to establish a fundamental understanding of metering technologies and the flow measurement principles behind them. In this regard, the thermo-physical properties of hydrogen mixed gases are crucial to understand and model hydrogen transportation and flow measurement processes. Thermo-physical properties of hydrogen-containing gas mixtures over a wide range of pressures and temperatures are pivotal to the design and optimisation of hydrogen production units, transportation, and storage processes.

Different strategies have been designed and developed for CCS and hydrogen applications to enable the move to net zero greenhouse gas emissions and mitigate the environmental impact of global warming. Consequently, the accurate determination of the phase envelope of CO2-rich and hydrogen containing streams and the respective thermophysical properties are essential and can be determined using thermodynamic models to optimally predict and model the fluid flow during transportation, conduct accurate flow measurement and ultimately control the processes throughout the CCS and hydrogen value chains.

While the ability to precisely determine the quantity of hydrogen geologically stored will be a fundamental foundation of a large-scale hydrogen value chain, it does present some unavoidable technical challenges. These require an integrated methodology to perform the real-time measurement of process stream composition, bulk flow rate and fluid properties of hydrogen-containing streams. While many of these technologies already exist, the future challenge of integration and economic feasibility must not be underrated.

About TÜV SÜD National Engineering Laboratory

The company is a global centre of excellence for flow measurement and fluid flow systems and is the UK's Designated Institute for Flow and Density Measurement, with responsibility for providing the UK's physical flow and density measurement standards

TÜV SÜD National Engineering Laboratory is a trading name of TUV SUD Ltd, a company of the TÜV SÜD Group, an international service organisation. More than 24,000 employees work at over 1,000 locations in about 50 countries to continually improve technology, systems and expertise.

They contribute significantly to making technical innovations such as Industry 4.0, autonomous driving and renewable energy safe and reliable.

More information

www.tuvsud.com/en-gb/nel

HeidelbergCement to build first carbon-neutral cement plant

The HeidelbergCement Group, which includes Norwegian Norcem and Swedish Cementa, announced that they plan to develop the world's first carbon-neutral cement plant in Slite, Gotland. When the carbon capture plant launches in 2030, it will capture almost 1.8 million tonnes of CO2 annually.

The installation at the Slite plant of HeidelbergCement's subsidiary Cementa will be scaled to capture up to 1.8 million tonnes of CO2 annually, which corresponds to the plant's total emissions. Additionally, the use of biobased fuels in the cement production at Slite will be increased in line with the Group's commitment to significantly raise the share of biomass in the fuel mix. The full-scale capturing of the plant's CO2 emissions is targeted by 2030.

The Slite plant of HeidelbergCement's subsidiary Cementa will be scaled to capture up to 1.8 million tonnes of CO2 annually

"We are delighted to see that HeidelbergCement is working on developing groundbreaking projects that decarbonise the industry, instead of wasting time on small-scale greenwashing projects," says Jonas Helseth, Director of Bellona Europa.

HeidelbergCement is currently building the world's first full-scale installation for carbon capture at the Brevik cement plant in Norway, capturing 400,000 tonnes annually or 50% of the plant's emissions from 2024 onwards.

"Based on the positive collaboration with the Norwegian government and other partners at our site in Brevik, we have now chosen to significantly ramp up our ambitions for a carbon capture installation in Sweden that is four times larger," said Giv Brantenberg, General Manager of HeidelbergCement Northern Europe. The planning for the plant in Slite will benefit significantly from the experience gained at Brevik.

The carbon capture facility will be built next to the existing plant in Slite, where three quarters of the cement used for concrete production in Sweden are currently produced.

The authorisation processes and the construction period are estimated to take just under ten years. A feasibility study, which has already been launched, will address critical issues related to technology selection, environmental impact, legal issues, financing, logistics, and energy supply. The captured CO2 will be safely transported to a permanent storage site offshore several kilometres down in bedrock.

Bellona said electrification and decarbonisation of industry were a part of its core focus areas.

"We have worked with HeidelbergCement for more than a decade to develop large-scale decarbonisation projects in the Nordic region and Europe. Hopefully, this solution will be implemented in other HeidelbergCement factories, especially in Germany, where the company is headquartered," said Helseth.

Bellona has been advocating for large scale climate action in industry for decades and is among the first NGOs to be concerned with developing carbon capture and storage as a weapon in the climate fight. Bellona has also collaborated with Norcem for many years, including the development of the project in Brevik.

In less than a year, we have gone from a situation where there were no climate solutions for cement production to not one but two large scale projects in Scandinavia that will considerably lower the climate footprint of the cement industry.

"We are happy with these projects. Doing tangible things is much more effective for the climate than just talking," says Helseth.

It is important to note that the development, permit processes and construction period are estimated to take just under ten years. Cementa has started an early-phase technology evaluation study. They appear to be allowing considerable time for piloting, studies, etc. However, this is not a fast-track project.

More information

www.heidelbergcement.com

www.bellona.org

Carbon Capture from cement production through mineralisation

Responsible for 8% of global greenhouse gas emissions and set to grow substantially, the cement sector is a key target for emissions reduction technologies. Stephen B. Harrison, sbh4 consulting, reviews some of the companies developing commercial carbon capture solutions.

Concrete is a composite material and the most frequently used building material worldwide. As a composite, it consists of three main components: cement, sand, and aggregate. The exact mixing ratio depends on the application and required strength, with a ‘normal mix’ being 1 part cement, 2 parts sand, and 4 parts aggregate (1:2:4). The annual global cement production in 2019 was 4.2 Giga Tonnes, of which 55% was produced in China.

Typically, concrete is produced locally and distributed within a 400 km radius. The fine and coarse aggregates are mined in local quarries and the sand must be of certain size and grain quality. Desert sands, for example those in the Sahara are not suitable. This has led to shortages in sand supply in some regions.

Up to 1 Tonne of CO2 is released into the atmosphere during the production of 1 Tonne of cement production. The raw material, mainly limestone, accounts for 65% of the emissions, and the fuel consumption of the production for the remaining 35%. Due to the large demand for concrete, the CO2 released from cement making accounts for 8% of global emissions – four times more than the global aviation industry.

Non-Hydraulic Cement

The most popular non-hydraulic cement in the past millennia was lime mortar, a mixture of lime, sand, and water. Limestone is burnt and decomposed into quicklime (carbon carbonate) and carbon dioxide above 900°C.

$$CaCO_3 \rightarrow CaO + CO_2$$

The quicklime is then mixed with water, and optionally sand, to form calcium hydroxide.

$$CaO + H_2O \rightarrow Ca(OH)_2$$

The lime mortar is then ready to use. After the excess water has evaporated, carbonation starts.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

This mineralisation takes carbon dioxide from the atmosphere but is very slow due to low partial pressure of CO2. In theory all CO2 which was released during limestone burning should eventually captured again at the end of the carbonation process.

Hydraulic Cement

Portland cement is the most common type of hydraulic cement. It has a higher strength than quicklime and is water resistant after curing is completed. Within the Portland cement production process limestone and clay, with a high silicon dioxide content, are mixed and preheated to 900°C where CO2 from the calcium carbonate is released as a gas. In the cement making rotary kiln, the components are sintered at temperatures of up to 1450°C into complex compounds such as tricalcium silicate.

$$3CaCO_3 + SiO_2 \rightarrow (CaO)_3{\cdot}SiO_2 + 3CO_2$$

The concrete curing starts with the mixing of cement and water. Hydration occurs during curing with the forming of calcium-silicate hydrates.

$$2((CaO)_3{\cdot}SiO_2) + 7H_2O \rightarrow 3(CaO){\cdot}2(SiO_2){\cdot}4(H_2O) + 3Ca(OH)_2$$

Under typical conditions it can take up to 28 days until 90% of the strength is reached. Over several decades atmospheric carbon dioxide diffuses into the concrete and converts the calcium hydroxide into calcium carbonate to further strengthen the concrete. However, the maximum theoretical carbon sequestration capacity is only 50% of the raw material CO2 emissions.

Carbon Cure – Carbon Dioxide Concrete Injection

The Canadian-based company Carbon Cure takes advantage of the sequestration capability of concrete by injecting an additional 1.5 kg of CO2 per Tonne of cement (or 0.482 kg CO2 per m^3 of concrete) during concrete preparation. This increases the strength of the concrete.

Since the strength increases, up to 16.9 kg of cement can be removed from each cubic metre of concrete and replaced with sand. Due to the high CO2 emissions of cement about 17 kg CO2 are saved per cubic metre of concrete. The cement avoidance accounts for 97.7% of total emissions reduction from this process, rather than the additional binding of CO2 to the cement.

The technology is readily available to reduce the CO2 emissions of concrete by 5% and can be scaled up immediately, as few changes are necessary in the concrete production process. Several reference projects exist in the US, with the Amazon HQ2 the largest project to date, achieving a net saving of 1,144 Tonnes of CO2.

Solidia – Alteration of the Cement Production

The US based company Solidia Technologies goes one step further and alters the cement production process itself. Instead of a 3:1 ratio of calcium carbonate to silica within Portland cement, the ratio was altered to a 1:1 and the burning temperature reduced to 1250°C instead of 1450°C. This creates synthetic calcium silicate (Wollastonite) instead of tricalcium silicate.

$$CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$$

Hence, the CO2 emissions in cement manufacturing reduces by approximately 30% including both the emissions from limestone and the energy demand. The Solidia concrete is cured at 60°C and ambient pressure mainly by CO2 with just a minimal amount of water, instead of up to 50% water at Portland cement-based concrete. This makes Solidia concrete favourable for precast concrete producers.

Considering the CO2 sequestration during curing plus the CO2 emission avoidance in cement production, the CO2 footprint can be lowered to 550 kg of CO2 per tonne of cement, which is equal to a reduction of about 50%. The technology is currently offered by LafargeHolcim in the US to precast concrete producers.

The cement industry is responsible for 8% global GHG emissions

Blue Planet – Carbon Dioxide Sequestered Aggregates

The two technologies presented so far have a certain GHG reduction potential. Nevertheless, there are still dedicated CO2 emissions associated with them. To sequester anthropogenic CO2 emissions Blue Planet suggested a new mineralisation process. It uses recycled concrete as base material. The crushed concrete contains the aggregate and cement fraction. During the process, the aggregate is upcycled and can be reused as aggregate in new concrete. Whereas the old cement fractions are mineralised with CO2 to form a new layer of calcium carbonate around the old cement parts, which basically acts as an incubation seed.

The CO2-sequesterd aggregate is used in addition to the upcycled aggregate in newly mixed concrete. In a first reference project the aggregates were used at the Interim Boarding Area B at San Francisco International Airport in 2016.

To store the CO2 as calcium carbonate, a raw material with a high calcium hydroxide or calcium oxide content is necessary. One example for this is Portland cement where the included calcium hydroxide is used for CO2 storage, like the Carbon Cure approach. Whereas other raw materials are fly ash (CaO 10-40%, MgO 0-10%) and steel slag (CaO 40-50%, MgO 5-10%). These materials contain also other metal oxides in high concentration, for example MgO. These can be also utilised to sequester carbon dioxide by the formation of carbonates (for example MgO + CO2 ◊ MgCO3).

The Blue Planet process reduces CO2 emissions by 100 kg per Tonne of concrete. This equates to about 220 kg CO2 per m^3 concrete. Considering a cement content of 320 kg per m^3 of concrete, this results in a reduction of about 0.65 Tonnes of CO2 per Tonne of Portland cement, and would therefore compensate for the raw material CO2 emissions of the cement production.

SkyMine – Turning Flue Gas into Baking Soda

Some processes above require modifications to the concrete and cement production process. The company CarbonFree has developed a new process, where the CO2 capture and sequestration can be directly connected to standard cement kilns. The flue gas is directed into an absorber column where CO2 is stripped using an aqueous sodium hydroxide solution.

$$CO_2 + 2\,NaOH \rightarrow Na_2CO_3 + H_2O$$

In a second step the sodium hydroxide is reacted with additional flue gas to produce sodium hydrogen carbonate, commonly known as baking soda.

$$Na_2CO_3 + H_2O + CO_2 \rightarrow 2\,NaHCO_3$$

The sodium hydroxide is produced on a chloralkali electrolyser. This electrolysis is responsible for 87% of the total energy demand, which reads as 8.3 GJ per Tonne of captured CO2. This is very similar to state-of-the art Direct Air Capture processes such as CarbonEngineering or Climeworks. If the avoided energy requirement to produce the electrolysis by-products (HCl, NaClO, NaOH) is accounted for in the overall carbon footprint analysis, then the energy demand for the CO2 sequestration drops to 2.8 GJ per Tonne of captured CO2.

In a first demonstration of the SkyMine process, 90% of the CO2 from a slipstream at the San Antonia cement factory is being captured. It has operated since 2016 and captures 75,000 Tonnes of CO2 annually. Food-grade baking soda from the process is supplied into the consumer market. Ultimately, the captured CO2 is released into the atmosphere in ovens during the baking process.

Global imperative to maintain the pace of innovation

The cement industry is responsible for 8% global GHG emissions. The worldwide market is expected to grow by up to 25% until 2050. Due to the sheer size of the cement industry and the lack of affordable alternatives to cement, it remains a global imperative to reduce the impact of CO2 emissions from this sector. Several technologies may have the potential to alleviate the problem, but the field is still open to see which carbon capture technology will dominate within this sector.

More information

sbh4.de

Unlocking Private Finance to support CCS Investments

A thought leadership report from the Global CCS Institute discusses the role of governments in creating an enabling investment environment for CCS and makes several recommendations for how to unlock private finance for projects.

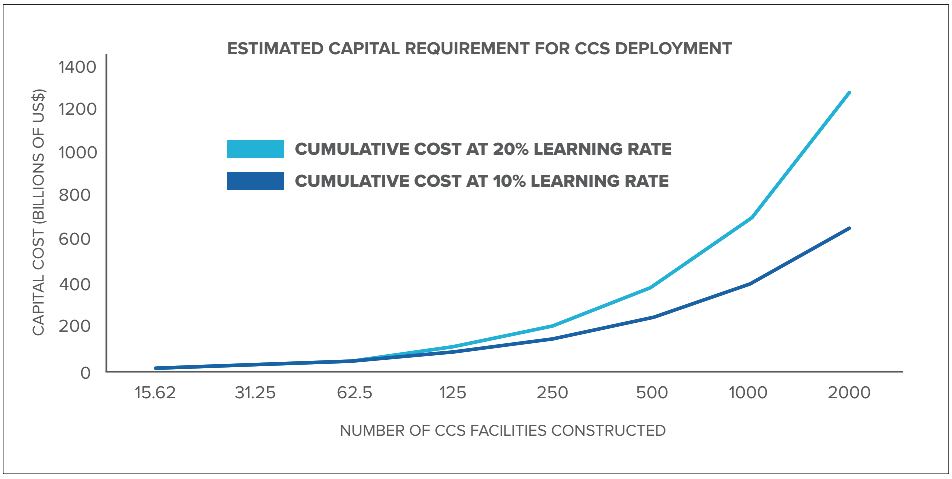
One model aligned with the goals of the Paris Agreement, the International Energy Agency's Sustainable Development Scenario (IEA-SDS) requires 15% of the world's emissions reductions to be achieved using CCS. The need for CCS in the IEA-SDS translates to a 100-fold increase in CCS capacity by 2050, for which the report estimates the total capital requirement to be between US$655 bn and US$1,280 bn.

The report examines:

• The potential for project finance to greatly accelerate investment in CCS capacity

• The application of green bonds to CCS projects in hard-to-abate sectors such as cement, fertilisers and chemicals

• The potential for climate finance to support CCS deployment in developing countries



Estimated costs for deploying CCS to meet emissions targets of the IEA-SDS. For each doubling of global CCS capacity, a reduction in cost, due to the learning rate, is achieved. These two scenarios estimate the overall cost for both a 20% and 10% learning rate

Conclusions

A critical step towards achieving CCS deployment at scale and in time to mitigate climate effects is for enabling policies to be implemented between now and 2030. These policies are key to attracting private sector investments, which will have to occur at a rate of tens of billions of US dollars a year, driven by enabling policies. These policies will lead to significant transition risks, and it is through them that incentives to drive private investments in CCS will occur.

At the same time, other government-led initiatives to support and enable these investments should also be prioritised. The role of specialist financiers will be crucial in supporting emitters that are unable to fund their CCS investments on their balance sheets. Governments can mandate specialist financiers to support investors through project finance.

Further, transition risks play the role of triggering engagement from the financial sector. To this end, it is also within the remit of governments to support the development of financial standards that recognise the eligibility of CCS investments as green or sustainable. This will not only lead to better terms of finance for CCS projects but will first make it far easier for financial institutions to engage with brown companies in their portfolio and for issuers to benefit from the huge potential of the green bond market.

While CCS deployment advances in developed countries, actions to support early deployment in developing countries will have to increase dramatically over the coming years. Climate finance has supported numerous mitigation technologies around the world, helping to create enabling environments for their deployment at scale.

If CCS is to be deployed in developing countries, where CO_2 emissions are growing most rapidly, a concerted effort is needed to ensure that developing countries are well supported when increasing their level of CCS readiness.

Firstly, vertical funds such as the Green Climate Fund and their agencies can provide concessional financing to support the capital needed to fund pilot projects that serve the purpose of derisking investments. Vertical funds can also support the development of policy mechanisms that place a value on CO_2 to create a business case for investing in CCS.

Secondly, international carbon markets are also a means through which CCS projects in developing countries can generate revenue. As international climate negotiations get underway at COP 26, the developments surrounding Article 6 of the Paris Agreement will help to ensure CCS projects in developing countries can generate revenue through carbon crediting mechanisms.

More information

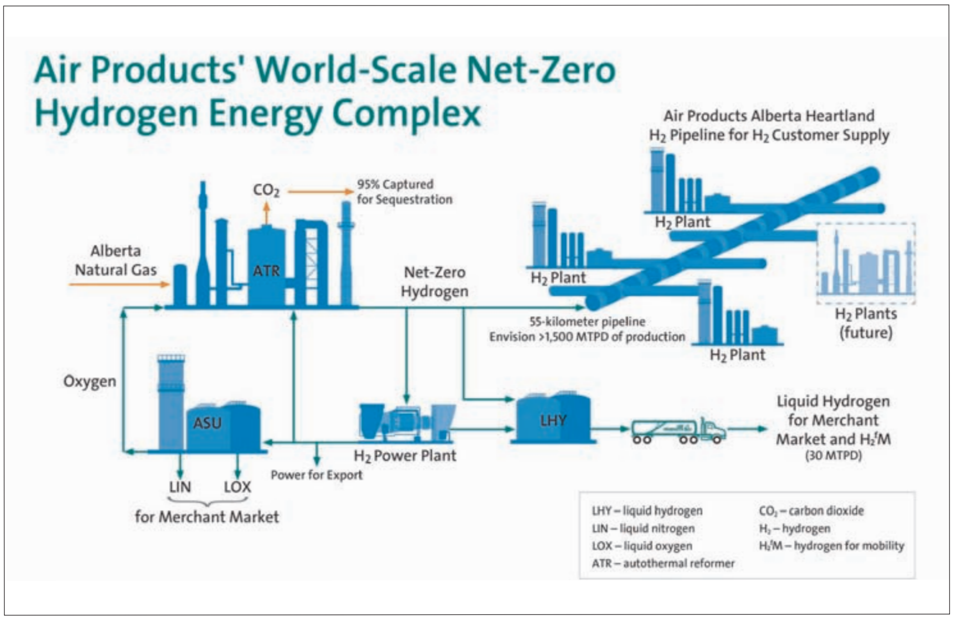
www.globalccsinstitute.com

Air Products plans multi-billion dollar net-zero hydrogen complex in Canada

In conjunction with the Government of Canada and the Province of Alberta the company announced a multi-billion dollar plan to build a landmark new net-zero hydrogen energy complex in Edmonton.

Canada's clean energy diversification strategy and regulatory framework make clear that hydrogen is a key enabler for carbon neutrality by 2050. Aligned with that vision, Air Products began work in 2018 on the core of this world-scale energy complex in Edmonton, which will begin with a transformative $1.3 billion (CAD) net-zero hydrogen production and liquefaction facility expected onstream in 2024.

The project relies on an innovative combination of well-established technologies to jump-start an ambitious transition to carbon neutrality. It will take advantage of Canada's abundant and low-cost natural resources, extensive infrastructure, highly skilled workforce, and innovative spirit to be a model for other jurisdictions around the globe.



The new facility will capture over 95 percent of the carbon dioxide (CO2) from the feedstock natural gas and store it safely back underground. Hydrogen-fueled electricity will offset the remaining five percent of emissions. The clean energy complex will help refining and petrochemical customers served by the Air Products Heartland Hydrogen Pipeline to reduce their carbon intensity.

The complex also marks a first in the wider use of hydrogen in Alberta, enabling the production of liquid hydrogen to be an emissions-free fuel in the transportation sector, and to generate clean electricity. This is expected to have a positive impact in lowering Alberta's carbon emissions.

Air Products, already Canada's leading hydrogen supplier, is also considering further investments in both existing and new hydrogen facilities in Alberta and across Canada, helping customers improve their sustainability performance while bolstering the hydrogen economy and Canada's energy transition.

The Edmonton project site was strategically selected to permit expansion of the energy complex, including replication of net-zero hydrogen production assets to meet growing demand. Air Products' existing Heartland Hydrogen Pipeline network was designed for growth and has the capability to more than triple current volumes.

Air Products' hydrogen business in Alberta is envisioned to reach over 1,500 tonnes of hydrogen production per day and achieve greater than three million tonnes per year of CO2 capture. Initially, Air Products will build, own, and operate a new net-zero hydrogen complex consisting of a:

• World-scale Auto-Thermal Reformer (ATR) hydrogen production facility, featuring Haldor Topsoe technology, to be built on a large project site in Edmonton that has room for expansion;

• Carbon capture operations capable of achieving 95 percent removal of CO2 from the complex. The CO2 will be permanently sequestered by leveraging the Wolf Carbon Solutions wholly-owned and operated Alberta Carbon Trunk Line;

• Power generation facility fueled 100 percent by hydrogen, including NovaLT16 turbines provided by Baker Hughes, to produce clean electricity for the entire facility and export to the grid, offsetting the five percent remaining CO2 to achieve the net-zero hydrogen facility design;

• 30 tonnes-per-day hydrogen liquefaction facility designed by Air Products, the first of such liquid hydrogen operations around the world to provide clean hydrogen to the growing industrial and mobility hydrogen markets across Western Canada;

• World-scale air separation facility, designed by Air Products to support the ATR operation and to produce clean liquid oxygen and nitrogen for the merchant industrial gas market; and

• Connection to Air Products' existing Alberta Heartland Hydrogen Pipeline network for enhanced reliability and phased decarbonization of the entire network.

More information

www.airproducts.com/bluebutbetter

Ørsted plans carbon capture at Avedøre Power Station in Denmark

Ørsted has identified the 100 MW straw-fired unit at the Avedøre Power Station in Copenhagen as the best point source of sustainable CO2 for the next phases of Green Fuels for Denmark.

The project is planned to reach a total capacity of 1.3 GW and have a carbon emission abatement potential of 850,000 tonnes yearly. If the project at Avedøre Power Station is realised, it could become Ørsted's first carbon capture facility. A future final investment decision for the carbon capture project is subject to the realisation of the parts of Green Fuels for Denmark that will produce e-methanol and e-kerosene.

Anders Nordstrøm, Vice President and head of Ørsted's hydrogen and Power-to-X activities, said,"If Green Fuels for Denmark is realised, Copenhagen could become a showcase example of how new and existing energy technology can be combined to deliver on the vast European ambitions for sustainable fuels. Denmark can leverage its district heating systems, large sources of sustainable carbon, and massive offshore wind resources to create a new industrial stronghold and supply sustainable fuels to Danish logistics companies that are leading the green transformation of heavy transport. Green Fuels for Denmark is an ideal flagship project to realise this potential, and the agreement with Avedøre Power Station to source sustainable CO2 underlines Ørsted's commitment to the project."

Ørsted owns and operates Avedøre Power Station. The combined heat and power plant consists of two wood pellet-fired units and a straw-fired unit that supply power to the Danish power grid and district heating to the Greater Copenhagen area. Ørsted and HOFOR recently announced an agreement that Ørsted will offtake the power production from HOFOR's planned 250 MW Aflandshage offshore wind farm for parts of the Green Fuels for Denmark project.

With the agreement to source renewable electricity in place, Ørsted has now identified the straw-fired unit at Avedøre Power Station as the best point source of sustainable carbon, and will now investigate the possibilities of advancing parts of the project's first phases in order to deliver substantial amounts of sustainable fuels well before the previously planned 2027 operation date of the second phase.

Avedøre Power Station in Copenhagen could be the first carbon capture facility in Denmark supplying CO2 for the next phase of Green Fuels for Denmark, an initiative to provide fuel from sustainable sources

Recently, Green Fuels for Denmark took an important step closer to realisation as the project became part of the process of being named an Important Project of Common European Interest (IPCEI) in the EU programme initiated to kick-off the hydrogen economy in the EU.

Green Fuels for Denmark is envisaged to be built in phases, beginning with approximately 10 MW, scaling up corresponding to the supply of electricity to reach 1,300 MW of total electrolysis capacity when fully developed.

While the first phase of Green Fuels for Denmark will exclusively produce hydrogen for heavy-duty road transport, the next phase is planned to combine the production of renewable hydrogen with carbon capture to produce sustainable methanol and e-kerosene for shipping and aviation, respectively.

Provided that a framework is established to promote the development of sustainable fuels, the 100 MW straw-fired unit at Avedøre Power Station could provide the amount of CO2 necessary for producing sustainable fuels in the next phases of Green Fuels for Denmark.

The straw-fired unit is fuelled by locally sourced agricultural by-products converting approx. 130,000 tonnes of straw each year to heat and power. The combination of using straw as fuel and utilising the surplus heat from both the carbon capture process and the Power-to-X process would result in up to 260 MW district heating, which would lead to both green and price-competitive district heating for the Greater Copenhagen area.

More information
orsted.com

Projects and policy news

SSE Thermal and Equinor join forces on Peterhead CCS power station

www.ssethermal.com

www.equinor.com

The companies will jointly develop a new low-carbon power station at Peterhead, which could become one of the UK's first power stations equipped with carbon capture technology.

Peterhead power station in Scotland could become one of the UK's first CCS power plants coming online as soon as 2026

Peterhead CCS Power Station is planned to be a new 900MW gas-fired power station fitted with carbon capture technology to remove CO2 from its emissions. By capturing up to 1.5 million tonnes (MT) of CO2 each year, the new station alone would achieve 15% of the UK Government's target to capture 10MT of CO2 annually by 2030.

As Scotland's only major thermal power station, SSE Thermal's existing Peterhead Power Station provides critical flexibility to the electricity system, supporting increased penetration from renewable generation while maintaining security of supply. Peterhead CCS Power Station, as a new decarbonised power station at the site, would continue to provide this essential flexible and efficient power in a net zero world.

Situated on Scotland's east coast, the Peterhead site in Aberdeenshire is ideally placed for carbon capture technology, with access to essential CO2 transport and storage infrastructure being developed through the well-advanced Acorn Project. The Acorn CO2 Storage Site, which will be used by the Acorn Project to safely store CO2, is located about 100km offshore in rock formations deep below the North Sea. Peterhead CCS Power Station and the Acorn Project both won funding from the UK Government's £171 million pot for the Industrial Decarbonisation Challenge Fund in March, as part of Scotland's Net Zero Infrastructure programme.

Given the readiness of carbon capture technology in power generation, projects like Peterhead CCS Power Station would stimulate the development of CO2 transport and storage infrastructure across Scotland, into which other energy and industrial emitters can then connect to capture and store their emissions..

The Peterhead CCS Power Station project is in the development stage and final investment decisions will depend on the progress of the necessary business models and associated infrastructure. With the appropriate policy mechanisms in place, the new station could come online by 2026, in line with Government ambitions for 'Track 1' industrial cluster projects and the proposed timelines for the Acorn Project

Venture Global launches LNG CCS project

www.ventureglobalIng.com

Venture Global LNG has announced plans to capture and sequester carbon at its Calcasieu Pass and Plaquemines LNG facilities.

The successful deployment of carbon capture and sequestration technology at Calcasieu Pass would be the first of its kind for an existing LNG facility in the United States.

Having concluded a comprehensive engineering and geotechnical analysis, the company is launching, subject only to regulatory approvals, a shovel-ready carbon capture and sequestration (CCS) project, compressing CO2 at its sites and then transporting the CO2 and injecting it deep into subsurface saline aquifers where it will be permanently stored.

Through this undertaking, Venture Global will capture and sequester an estimated 500,000 tons of carbon per year from its Calcasieu Pass and Plaquemines liquefaction sites. In addition, the Company anticipates using similar infrastructure to capture and sequester 500,000 tons of carbon per year from the CP2 LNG facility once permitted. Altogether, Venture Global plans to sequester 1 million tons of carbon per year, the equivalent of removing nearly 200,000 cars off the road each year for 20 years.

"From driving down the cost of LNG to driving down our carbon footprint, Venture Global continues to execute on our mission to constantly innovate in order to deliver the best product possible to our customers," said Venture Global CEO Mike Sabel.

"Through this historic carbon capture and sequestration project, we will build upon our existing state-of-the-art technology to develop even cleaner LNG at our facilities to displace coal around the world. Our location in Louisiana uniquely positions us to pioneer the deployment of this technology due to geology that can support industrial scale injection and storage of CO2. Through the continued leadership of Governor John Bel Edwards, Louisiana will become the national hub for innovative energy technology to tackle climate challenges and Venture Global is proud to partner with him in these efforts."

Linde to build CO2 Capture Project for Springfield Power Plant

www.leamericas.com

Linde Engineering Americas has been selected by the U.S. Department of Energy's National Energy Technology Laboratory (NETL) to install and test a 200 tons per day CO2 capture pilot plant at the City Water, Light & Power (CWLP) power plant in Springfield.

Through a funding award made to the Board of Trustees of the University of Illinois, the project will be executed in collaboration with BASF, University of Illinois at Urbana Champaign, CWLP and ACS. The successful construction and operation of this plant will provide a means to demonstrate an economically attractive and transformational capture technology.

According to company officials, the project will showcase Linde's post-combustion CO2 capture technology capabilities jointly developed utilizing BASF's OASE® blue gas treatment technology.

"We're excited about this opportunity to feature the CO2 capture technology we've developed with BASF," said Dominic Cianchetti, Senior Vice President, Region Americas. "There are many commercial uses for this technology, and this project will help guide future discussions about the viability of those possibilities."

The large pilot project is a major milestone for the future of carbon capture technology's commercial viability.

Asia CCUS Network launched

www.asiaccusnetwork-eria.org

www.meti.go.jp

Thirteen countries (all ASEAN member states, Australia, the United States of America and Japan) and more than 100 companies, research institutions, and international organizations have so far expressed their intention to participate in the network.

The Asia CCUS Network is an international industry-academia-government platform aiming at knowledge sharing and improvement of the business environment for utilization of carbon capture, utilization, and storage (CCUS) throughout the Asia region.

"Carbon Capture, Utilisation and Storage: The Opportunity in Southeast Asia", a special report newly released by the IEA on June 21, states that CCUS will play a significant role in the Southeast Asian region, where demand for fossil fuels will remain high.

CO2 capture in Southeast Asia will have to reach at least 35 Mt CO2 in 2030, and will need to exceed 200 million tons by 2050. In order to achieve this level of CCUS deployment, it is estimated that by 2030, investment of more than US$1.0 billion per year is required.

In this context, the Ministry of Economy, Trade and Industry (METI) and the Economic Research Institute for ASEAN and East Asia (ERIA) held "The 1st Asia CCUS Network Forum" on June 22nd and 23rd, 2021.

It was also announced that 13 countries (all ASEAN member states, Australia, the United States of America and Japan) and more than 100 international organizations, companies, financial and research institutions that share the vision of CCUS development throughout the Asian region have expressed their intention to participate in its activities.

In addition, Minister Kajiyama explained the following activities as showcases of Japan's contribution to the development of CCUS in the Asian region;

• Developing a vision for inter-industry collaboration at the Tomakomai CCUS and Carbon Recycling Demonstration Center, where oil and gas fields, power plants, manufacturing industry, biomass and CCS demonstration centers are located

• The development of innovative capture technologies and the demonstration of long-distance CO2 transportation by ship, for which the adoption of the operator was announced today.

• Toward the realization of CCUS demonstration utilizing the Joint Crediting Mechanism (JCM) between Indonesia and Japan, joint studies by Japanese and Indonesian companies will be launched on the basis of memorandum of cooperation and joint study agreement.

• International collaboration with the United States and Australia to demonstrate the application of Japanese monitoring and injection technologies

• Providing practical guidance for geological CO2 storage through the Asia CCUS Network (the first issue is scheduled to be published in August 2021)

Dastur awarded design contract for large-scale steel CCUS

www.dasturenergy.com

Dastur has been awarded a US Department of Energy (US DOE) funded study for the design and engineering of a carbon capture project for a large integrated steel producer in North America.

The project is designed to enable the production of low-carbon emissions steel through CO2 capture of up to 2 mtpa from the available blast furnace gases. This is the first industrial-scale carbon capture project for the steel sector in North America. Dastur is the Prime Recipient of the Award and will be supported by ION Clean Energy and University of Texas at Austin's Jackson School of Geosciences.

Addressing a major share of carbon emissions in the integrated steelmaking process, the project aims to design an industrial scale and cost-effective solution for the capture and disposition of CO2 and provide a hydrogen-rich gas stream for meeting the energy needs of the host steel plant. Dastur's proposed approach and design targets to bring down the cost of capture and disposition to mid $40/tonne of CO2, a significant improvement over incumbent solutions in the 60-100 $/tonne range.

The Biden Administration, in its "2030 Greenhouse Gas Pollution Reduction Target", has announced that "The United States can address carbon pollution from industrial processes by supporting carbon capture as well as new sources of hydrogen - produced from renewable energy, nuclear energy, or waste - to power industrial facilities."power

Along with its partners, Dastur will engineer a flexible, scalable and cost-effective industrial-scale carbon capture & management solution. A successful & cost-effective industrial-scale solution could serve as a reference for other integrated steel plants in the USA, as well as the major steel-producing geographies like China, Japan, South Korea, and India, where steel capacities are largely blast furnace based.

ABB Smart Sensors unlock valuable data

A new carbon capture plant in the UK has chosen smart sensor technology from ABB to provide remote condition monitoring on critical motors, thereby reducing the number of man-hours required on site.

Smart sensor technology from ABB has unlocked valuable data at the UK's largest carbon capture facility

Tata Chemicals Europe's (TCE) Winnington site has installed 11 High Performance Smart Sensors from ABB which will enable it to identify trends in the performance and condition of a series of motors across the facility. Using the data, which is collected autonomously by the sensors, the plant can identify faults, reduce unplanned stoppages, minimise the duration of any outages, and plan maintenance tasks in advance of them becoming critical to the ongoing operation of the site.

Matthew Shepherd, Technical Manager for Tata Chemicals Europe in the UK, said, "The Smart Sensors enable remote condition monitoring of our motor-driven processes, enabling us to greatly reduce the number of manned hours on site. The data provides an ongoing trend view of vibration, temperature and bearing condition, and a host of other operational parameters, so we can react before problems arise."

Due to the nature of the process, the sensors are required to be ATEX certified as a fault condition within the system could potentially create a hazardous environment. The data collected by the sensors is monitored regularly and provides site engineers with email and mobile app notifications over any changes it recognises.

The installation is part of a pilot scheme, with Tata keen to move towards more data-driven production methods. "The ability to monitor trends was a key motivation for us with this project," added Shepherd; "From the start, we're able to establish a baseline of what an optimal process looks like so we will always have a benchmark. This means we can look at process efficiencies and optimisations whenever parameters are changed and monitor the effect they have on other processes at the plant."

Steve Hughes, Digital Lead for ABB Motion UK, added, "The installation of High Performance Smart Sensors at the Winnington carbon capture facility proves the concept of Industry 4.0 in a real-life application. The sensors monitor trends that the engineering team there can use to predict when a particular motor is likely to require attention. Employing this approach means the operations team can incorporate preventive maintenance measures into its planned stoppages, reducing the time taken fixing unplanned outages."

About the project

The first large-scale CCU project of its kind in the UK, the TCE plant also represents a world first in capturing and purifying carbon dioxide from power generation plant emissions for use as a key raw material in the manufacture of high purity sodium bicarbonate.

The project could help pave the way for other industrial applications of carbon dioxide capture and is an important step in decarbonising industrial activity. The TCE CCU plant will play a major role in supporting the Government's recently announced target of net zero carbon emissions by 2050.

In a unique application of CCU technology, the TCE plant will capture carbon dioxide from the flue gases of TCE's 400MWheat, 96MWe gas-fired, combined heat and power plant, which supplies steam and power to our company's Northwich operations and other industrial businesses in the area.

The CCU plant will then purify and liquify the gas for use in the manufacture of sodium bicarbonate. Deploying CCU technology will reduce emissions, as captured CO2 will be used in the manufacturing process rather than being emitted into the atmosphere.

TCE's CCU plant will be capable of capturing and producing up to 40,000 tonnes per year of carbon dioxide and will reduce TCE's carbon emissions at the CHP plant by 11% and support the annual manufacture of over 120,000 tonnes of high purity sodium bicarbonate which is used in applications such as haemodialysis, pharmaceuticals, food, animal feed and many other applications.

From 2021, Tata Chemicals Europe will be making one of the lowest carbon footprint sodium bicarbonate and sodium carbonate products in the world.

More information

www.abb.com

tatachemicalseurope.com

Capture and utilisation news

Yara and JERA collaborate on green ammonia

www.jera.co.jp

www.yara.com

The companies will develop blue and green ammonia supply chains to feed zero emission power projects in Japan.

Yara International ASA, a leading global ammonia player and JERA Co., Inc, Japan's largest power generation company, have signed a Memorandum of Understanding to collaborate on the production, delivery and supply chain development for blue and green ammonia, to enable zero-emission thermal power generation in Japan.

Japan recently announced plans to introduce ammonia into the fuel mix for thermal power generation, as part of its measures to cut CO2 emissions and reach carbon neutrality by 2050. As part of its Green Growth Strategy, the government targets ammonia imports of 3 million tonnes by 2030.

"This ground-breaking collaboration aims to decarbonize JERA's power production and provide Yara with a footprint in the strategically important Japanese market. Building blue and green ammonia value chains is critical to enabling the hydrogen economy, and collaborating with a key player like JERA marks a milestone in leveraging Yara's global capabilities," says Svein Tore Holsether, President and Chief Executive Officer of Yara.

Ammonia does not emit carbon dioxide during combustion and is seen as an effective future energy source. Blue ammonia is derived from a carbon capture and storage process (CCS), while green ammonia is produced carbon free by using hydrogen sourced from renewable energy as feedstock. The term clean ammonia comprises both blue and green ammonia.

Under the MoU, Yara and JERA are targeting collaboration in the following areas:

• Supply and development of new ammonia demand in Japan including power generation purpose

• Sequestration of already captured CO2 (CCS) at Yara's ammonia plant in Pilbara, Australia, enabling the production and supply of blue ammonia to JERA

• New clean (blue and green) ammonia project development

• Optimization of ammonia logistics to Japan

JERA is the largest power generation company in Japan, producing about 30% of Japan's electricity. The Tokyo-based company is committed to establishing green fuel supply chains to achieve zero CO2 emissions from its operations in Japan and overseas by 2050.

Yara is a world leader in ammonia, with long experience and leading positions within global ammonia production, logistics and trade. The Oslo-based company produces roughly 8.5 million tonnes of ammonia annually. Yara employs a fleet of 11 ammonia carriers, including 5 fully owned ships, and owns 18 marine ammonia terminals with 580 kt of storage capacity – enabling it to produce and deliver ammonia across the globe.

Yara recently established a new Clean Ammonia unit to capture growth opportunities in emission-free fuel for shipping and power, carbon-free fertilizer and ammonia for industrial applications.

Nickel atom aids carbon dioxide reduction by RIKEN

www.riken.jp

Scientists are closer to finding ways to convert carbon dioxide in the atmosphere into industrially useful chemicals thanks to a RIKEN study.

The study looked at how nature converts carbon dioxide into more complex organic compounds—one of the processes underpinning the origin of life.

Finding an energetically efficient means to convert carbon dioxide gas into useful compounds is highly attractive for reducing the emission of the greenhouse gas in an economically viable way. In nature, carbon dioxide is converted into carbon monoxide and then into more complex organic compounds through reactions that are most likely linked to the origin of life on Earth.

These reactions can follow different pathways, but a particularly efficient one employs the enzyme carbon monoxide dehydrogenase (CODH), which helps reduce the energetic costs associated with the first step of the reaction: the reduction of carbon dioxide into carbon monoxide. Understanding the catalytic mechanism of the CODH enzyme could thus pave the way to environmentally friendly technological applications as well as offer important insights into the origin of life on our planet.

Every enzyme has a specific active site where the relevant reactions occur. Now, Ryuhei Nakamura of the RIKEN Center for Sustainable Resource Science (CSRS) and colleagues have proposed that a specific atom, nickel, is key to the reaction mechanism that take places at the active site of the CODH enzyme.

"CODH is a rare enzyme that uses a nickel-iron sulfide active site instead of the more common iron sulfide clusters," explains Hideshi Ooka, co-author of the article. "While our group and others have already reported that adding nickel into iron sulfides improves the efficiency for carbon dioxide reduction, the reason why nickel is important wasn't known due to the lack of in situ spectroscopic studies," says Ji-Eun Lee, also of CSRS.

The team used three inorganic analogs of the CODH active site—one featuring iron and sulfur and two featuring nickel, iron and sulfur—and followed the carbon dioxide reduction on the three analogs using infrared spectroscopy while varying the applied electric potential.

Carbon dioxide reduction occurred only in the presence of nickel, which binds to carbon while iron binds to oxygen. As the potential was increased, the iron sulfur and nickel cluster catalyzed the further reduction of carbon monoxide into the formyl group, which was then converted into methane and ethane.

Through their work, Nakamura and coworkers have provided a molecular-level understanding behind nickel-enhanced reduction of carbon dioxide, offering important insights for the development of biomimetic catalysts.

"Our results also show that carbon dioxide reduction is possible on the surface of minerals, suggesting that nickel-iron sulfides may have contributed toward prebiotic fixation of carbon dioxide," says Nakamura.

Transport and storage news

TECO 2030 and Chart developing CO2 capture and cryogenic storage on ships

teco2030.no
www.chartindustries.com

The companies have signed an MoU to jointly develop technological solutions that will capture carbon dioxide emitted by ships and subsequently store it in liquid form.

The agreement between the Norwegian company TECO 2030 and the American manufacturer Chart Industries involves the joint development of onboard carbon capture solutions for ships using the Cryogenic Carbon CaptureTM (CCC) technology developed by SES, which was acquired by Chart Industries, Inc. in December 2020.

“When the new CO2 capture integration that we are collaborating with Chart Industries, Inc. and Sustainable Energy Solutions (SES) on is ready, it will enable ships to capture and store the CO2 that they would otherwise have emitted into the air, and which would thereby have contributed to climate change,” says Stian Aakre, CEO of TECO 2030 AS.

The technology, which uses Chart Industries' expertise in cryogenic equipment and systems along with SES’s patented and proven technology, will separate the CO2 from the ships’ exhaust gases, resulting in a high purity liquid CO2 product. The liquid CO2 is then stored onboard in cryogenic storage tanks until the ship reaches port.

When it has been offloaded from the ship, the CO2 can then either be permanently stored in geological formations underground or be put to beneficial use in CO2-consuming industries, such as the agricultural, industrial, energy, or food and beverage sectors.

When fully developed, the carbon capture solution will become available as a key element in the TECO 2030 Future Funnel, an exhaust gas cleaning system for ships developed by TECO 2030.

“At TECO 2030, our ambition is to help ships become more environmentally friendly as well as enable them to comply with emerging climate legislation,” says Aakre. “We believe carbon capture for ships will become one of several measures needed for the shipping industry to reach global decarbonisation goals.”

Navigator looking to expand Midwest carbon capture pipeline

www.navigatorco2.com

Navigator is actively looking to expand the capacity of the pipeline and proceed with multiple sequestration sites, creating an injection capacity of up to 12 million metric tonnes per year.

The proposed CCS project seeks to provide biorefineries and other industrial participants a long-term, economic path to materially reduce their carbon footprint by capturing and transporting CO2 through 1,200 miles of pipeline across five Midwest states to a permanent sequestration site.

Based on extensive feedback from potential customers representing diverse emissions sources, and in an effort to provide a holistic solution for multiple industries, Navigator is actively looking to expand the capacity of the pipeline.

Navigator previously announced its partnership with BlackRock Global Energy & Power Infrastructure Fund to develop the CCS in Nebraska, Iowa, South Dakota, Minnesota and Illinois; Valero Energy Corporation is the anchor customer. The proposed system plans to transport liquefied carbon dioxide through the pipeline to a sequestration site.

At full capacity, the CCS will have the ability to capture and store enough CO2 to be the equivalent of removing approximately 2.6 million cars from the road per year or planting 550 million trees per year or eliminating carbon footprint of Kansas City 1.5 times over.

Navigator will use the information received during the non-binding open season to continue working with interested shippers on binding commercial agreements. The framework of these agreements will form the basis to launch the binding open season, expected early June 2021.

This CCS project is one of the first large-scale, commercially viable, carbon pipelines to be developed in the United States. Plans are underway to further expand the scope of the project as needed to accommodate future incremental customer demand. Navigator anticipates the CCS project to begin operations in phases beginning in late 2024.

CGG and Geoptic collaborate on CO2 downhole monitoring

www.cgg.com

www.geoptic.co.uk

CGG has signed an R&D collaboration agreement with Geoptic to jointly research and assess a novel borehole solution for monitoring the spread of CO2 in subsurface storage sites for CCS.

The agreement focuses on developing a new version of Geoptic’s DIABLO muon tracking tool specifically for CCS applications. Geoptic deploys DIABLO as part of its pioneering use of cosmic ray muons to passively and non-intrusively image the internal structure of objects. It has already gained award-winning experience in deploying muon technologies for subsurface surveys, such as its innovative imaging through the overburden of railway tunnels.

Building on this success, Geoptic is developing muon sensors suitable for use down boreholes for the imaging of CCS projects several kilometers underground, as they can be especially useful for environmentally sensitive areas. Application of these sensors could expand to include surveying construction sites, structural monitoring, mining and other subsurface monitoring arenas.

This collaboration is part of CGG’s initiative to further its leadership around technologies that advance the Measurement, Monitoring and Verification (MMV) of CO2 storage. CGG will draw on its extensive expertise in geophysical imaging and integrated geoscience solutions to process and model the data acquired by Geoptic’s downhole tools. The collaboration is focused on delivering a new continuous long-term subsurface monitoring solution that will reduce the risks associated with CO2 leakage and enhance the safety of CO2 storage projects.

Professor Jon Gluyas, Chairman and co-founder of Geoptic, said, “Geoptic was launched in 2019 by the universities of Durham, Sheffield and St Mary’s following the successful development and testing of muon detectors that could operate in the deep, hot and hostile environments found deep below the Earth’s surface and typical of planned CO2 storage sites beneath the North Sea.”

Old oil fields may be less prone to induced earthquakes and safe for CO2

A new study published in Geology explores why part of a heavily produced oilfield in the U.S. has earthquakes, and part of it doesn't.

For the first time, the authors demonstrate that the influence of past oil drilling changes stresses on faults in such a way that injecting fluids is less likely to induce, or trigger, earthquakes today.

The study focuses on the Delaware Basin, an oil- and gas-producing field spanning the border between West Texas and New Mexico. Drilling there has taken place since at least the 1970s, with over 10,000 active individual wells dotting the region. There, Stanford geophysicists No'am Dvory and Mark Zoback noticed an interesting pattern in seismic activity. Recent shallow earthquakes were mostly located in the southern half of the basin, while the northern half is seismically quiet, despite shallow wastewater injection occurring across the basin.

"The compelling question, then, is why are all the shallow earthquakes limited to one area and not more widespread?" Zoback says. Earthquakes can be induced by injecting fluids like wastewater underground. When wastewater is injected into the rocks, pressures increase, putting the rocks and any faults that are present under higher stress. If those pressures and stresses get high enough, an earthquake can happen.

Earthquakes from injection in the southern Delaware Basin tend to be shallow and relatively low-magnitude, typically strong enough to rattle the dishes, but not enough to cause damage. However, if deeper faults are activated, higher-magnitude earthquakes can occur and cause damage. For example, in March 2020, a magnitude 4.6 earthquake rumbled in Mentone, Texas, likely due to deep injection that interacted with faults in the crystalline basement rock around five miles belowground.

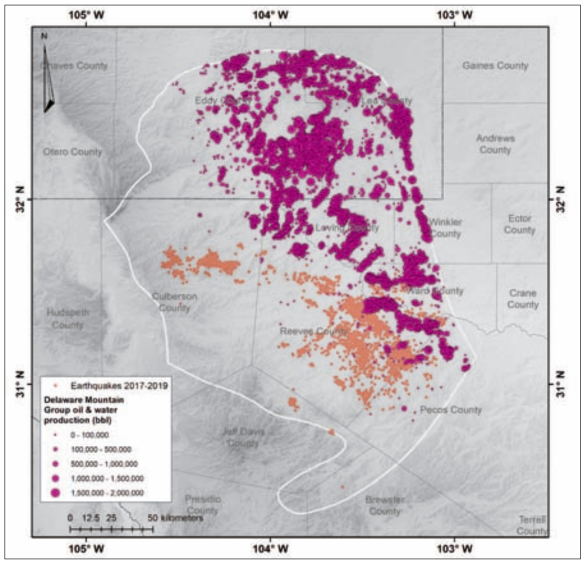
"The size of an earthquake is limited by the size of the fault that slips," Dvory explains. Where faults are shallow and small (just a few kilometers in size), quake magnitudes tend to be small. "You can still feel it, but it's less dangerous."

Minimizing the risk of earthquakes is a goal for any subsurface operation, whether it's oil and gas production or carbon sequestration. That made the Delaware Basin, with its odd pattern of earthquakes, a great target for Dvory and Zoback. It was a natural experiment in geomechanics, the "why" behind induced earthquakes.

To decipher the pattern, Dvory and Zoback first modeled the underground pressures needed to cause faults in the basin to slip and connected those values to estimated stress values. Once they had established that baseline, they calculated the pore pressures around the Delaware Basin. Their results showed a clear pattern: geologic formations in the northern basin where hydrocarbons had previously been produced had lower pore pressures than in "unperturbed" rock, and there were no earthquakes. The southern basin, which had almost no previous production from the same formations, had higher initial pressures and earthquakes.

"In some areas we have evidence of oil and gas development from even the 1950s," Dvory says. "Where there was significant hydrocarbon production, pressure was depleted, and the formations essentially became more stable." Now, when fluids are injected back into those 'stable,' previously drilled rocks, the starting pressure is lower than the first time they were drilled.

"So where oil production occurred previously, current injection results in significantly lower pressure such that it's much less likely to trigger earthquakes," Zoback explains. "It's not inconceivable that at some point, if you injected enough, you could probably cause an earthquake. But here in the area we study, we are able to document that what happened previously strongly affects how current operational processes affect the likelihood of earthquake triggering."



Earthquakes in the southern Delaware Basin (red dots) occur where there has been no historical production from the Delaware Mountain Group (purple circles, the size of the circle indicates the volume of oil and water produced). Credit: Dvory et al.

Targeting these sites of past oil production, with their lower earthquake risk, could be a good approach for carbon sequestration.

"We have a global challenge to store enormous volumes of carbon dioxide in the subsurface in the next ten to twenty years," Zoback says. "We need places to safely store massive volumes of carbon dioxide for hundreds of years, which obviously includes not allowing pressure increases to trigger earthquakes. The importance of geoscience in meeting this challenge can't be overstated. It's an enormous problem, but geoscience is the critical place to start."

More information

www.geosociety.org/gsa

Midwest Regional Carbon Sequestration Partnership Research completed

Battelle and its team of partners have successfully concluded the CCUS research associated with the Midwest Regional Carbon Sequestration Partnership (MRCSP), paving the way forward for commercial deployment.

Battelle led MRCSP in three phases, starting with the initial characterization phase in 2003, moving to multiple small-scale pilot tests in the validation phase in 2005 and culminating in the large-scale development phase starting 2008. Now, the focus moves to commercialization and expanded regional initiatives, especially focused on the storage/sequestration portion of the climate change mitigation approach.

"We are so pleased to have completed this work," said Dr. Neeraj Gupta, MRCSP Principal Investigator and Battelle's Technical Director for Carbon Management. "We met all our objectives and stored more than two million tons of carbon dioxide in three phases, effectively and safely. The lessons learned from MRCSP research are now being applied to a number of commercial projects."

A comprehensive series of MRCSP reports have now been approved by the United States Department of Energy (DOE) and can be downloaded from the announcements page of the newly formed Midwest Regional Carbon Initiative (MRCI). These include a Final Technical Report, topical reports on characterization, modeling, monitoring, life-cycle assessment, and regional scale-up for the large-scale test in Michigan. Also included are a series of topical reports on selected regional assessments in the 10-state MRCSP region. In addition, the MRCSP team has published extensively in peer-reviewed journals and conference proceedings to facilitate knowledge sharing.

"We congratulate Battelle and their partners on the MRCSP's important accomplishments throughout all three phases," said Dr. Jennifer Wilcox, Acting Assistant Secretary for Fossil Energy and Carbon Management. "These partnerships will be critical to advancing the deployment of carbon capture and dedicated storage of CO2, we look forward to working with the MRCI to help commercialize those critical technologies."

Key aspects to the MRCSP program - MRCSP strived to produce stakeholder education and outreach materials to communicate the key findings and help define a path forward for successful deployment of CCUS

The MRCSP work has been funded primarily by the U.S. Department of Energy's Fossil Energy program through the National Energy Technology Laboratory, with significant co-funding from the Ohio Coal Development Office in the Ohio Department of Development, Core Energy's in-kind contributions, and numerous other partners. The MRCSP was a collaboration of nearly 40 government, industry and university partners joined to assess the technical potential, economic viability and public acceptability of CCUS for DOE. The field research was performed on the oilfield sites owned and operated by Core Energy.

"We were proud to collaborate with Battelle, NETL and the other MRCSP stakeholders on this very practical and foundational research over the last 12 years," said Bob Mannes, President of Core Energy. "The operational expertise of the Core Energy team was vital to this field demonstration proving the safe and secure injection of over two million tons of CO2 in Michigan. This characterization work will be foundational to commercial projects in the future as it demonstrates that Michigan has the capacity to safely store hundreds of years of carbon emissions."

In transitioning to the next phase of CCUS development, the MRCSP program has evolved into the MRCI, led by Battelle and the Illinois State Geological Survey. MRCI aims to advance CCUS research by addressing key technical challenges, obtaining and sharing data to support CCUS, facilitating regional infrastructure planning and performing regional technology transfer. The MRCI study region covers 20 states in the Midwest and Northeast United States and includes collaboration with the state geological surveys, industry, and universities across the region.

The Midwest part of the U.S. is undergoing a major energy transition, which includes continued reliance on coal-based energy, but with a sharply increasing natural gas use and potential for deployment of new energy technologies. All of these will require use of CCUS for disposition of carbon dioxide. Meeting this demand for carbon dioxide storage will require characterization, qualification, and development of numerous storage sites associated with carbon capture. These future projects also offer a major employment opportunity for people currently engaged in oil and gas related industries.

More information

www.midwestccus.org

www.battelle.org

Pembina and TC Energy partner on 'world-scale' CCS pipeline, storage

The companies will jointly develop a large-scale carbon transportation and sequestration system capable of transporting more than 20 million tonnes of CO_2 annually throughout Alberta.

By using the existing pipeline network and a newly developed sequestration hub, the Alberta Carbon Grid will help Alberta-based industries to effectively manage their emissions and contribute positively to Alberta's lower-carbon economy and create sustainable long-term value for Pembina and TC Energy stakeholders.

Designed to be an open-access system, the ACG will serve as the backbone of Alberta's emerging carbon capture utilization and storage industry, connecting the Fort McMurray region, the Alberta Industrial Heartland, and the Drayton Valley region to key sequestration locations and delivery points across the province, and serving multiple industries.

For Canada to achieve its enhanced climate targets, including a 40-45% reduction in greenhouse gas emissions below 2005 levels by 2030, CCUS technology and infrastructure will need to play a vital role.

The Alberta Carbon Grid

Through redeployment, retrofits using proven technology, recapitalization, and optimization of surplus capacity across the collective pipeline systems, including, subject to closing of the transaction, through Pembina's proposed acquisition of Inter Pipeline Ltd., ACG is designed to connect the province's largest sources of industrial emissions to a sequestration location north-east of Redwater, Alberta. The principal segments include:

• North Leg: Pembina and TC Energy plan to retrofit existing pipeline systems, combined with new build expansion to connect the Oil Sands to a sequestration hub. Initial hydraulics indicate a design capacity of up to 40,000 tonnes of CO_2 per day, allowing a significant portion of emissions from the Fort McMurray area to be transported to a sequestration location;

• Central Leg: Pembina and TC Energy plan to retrofit existing pipeline systems, combined with new gathering laterals, to provide interconnectivity in the Alberta Industrial Heartland and gather and deliver CO_2 from and to industrial sources with initial hydraulics indicating a design capacity of 10,000 to 20,000 tonnes per day;

• Southwest Leg: Pembina and TC Energy plan to retrofit existing pipeline systems, combined with new build expansion, to form the southwest leg of the system. This portion would capture CO_2 from power generation facilities in the region with possible capacity of 10,000 to 20,000 tonnes per day;

• Future Legs: With customer support, Pembina and TC Energy have identified multiple opportunities to extend ACG into other regions, for example Joffre, Christina Lake, Cold Lake or Swan Hills, enabling future expansions and greater connectivity;

• Sequestration: A reservoir near Fort Saskatchewan has been selected, where large volumes of CO_2 will be sequestered in the Basal Cambrian Sands. Permit applications have been prepared and the companies have worked with the Government of Alberta to obtain support for the Project and set a path to obtain sequestration rights. Initial studies indicate this reservoir will be capable of sequestering more than 2,000,000,000 tonnes of CO_2, which represents many decades of sequestration capacity;

• Partnership: Pembina and TC Energy are open to other infrastructure owners with suitable existing infrastructure to join the partnership with a view to enhancing the capability and reach of the Project.

Key Benefits of the Alberta Carbon Grid:

• World-Scale Carbon Capacity: The open-access system is being designed with the ability to scale up to more than 60,000 tonnes per day of capacity, or 20,000,000 tonnes per annum, representing approximately 10 percent of Alberta's industrial emissions.

• Interconnectivity: Pembina and TC Energy view the ACG as a multi-sector solution with interconnectivity between multiple key hubs for expanded emissions reductions.

• Environment, Cost and Time Benefits: Utilizing existing assets dramatically accelerates timing, greatly reduces cumulative environmental and community impacts, and is significantly less capital intensive than building a new pipeline. Pembina and TC Energy are targeting the first phase to be operational as early as 2025, with the fully scaled solution complete as early as 2027, subject to regulatory and environmental approvals.

• Economic Development: The construction and operation of the ACG, along with other investments in CCUS technology and infrastructure, will create an entirely new business platform for each company and create new high-value jobs and support economic growth across Alberta.

• Safe & Reliable Operations: World-leading experts have been engaged to evaluate technical and operating conditions of using existing pipeline systems to transport CO_2. The companies have the skills and experience to safely operate these kinds of systems as the characteristics of CO_2 are very similar to other products which are safely transported today, such as specification ethane. The completed feasibility study demonstrates that ACG is achievable while maintaining high standards of safety and reliability. The companies have been working with regulators to advance the Project.

• Customer-Focused Solution: With multiple inlets and outlets, customers will have flexibility to decide delivered CO_2 end-uses including industrial processes and sequestration.

More information

www.pembina.com

www.tcenergy.com

CSIRO has been developing amine absorbent technology for over fifteen years