Carbon Capture Journal

CCUS in the U.S.

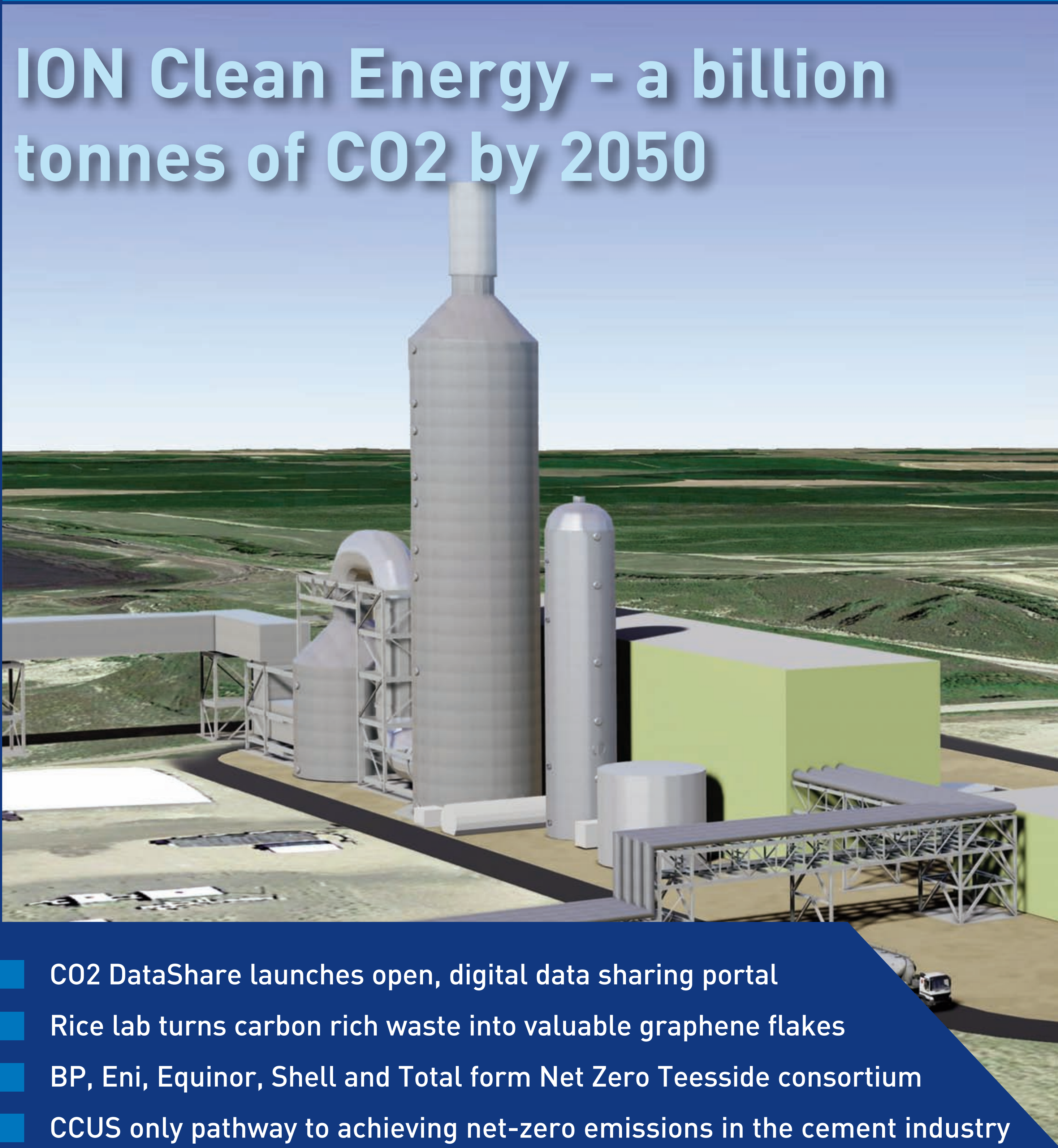
CCUS: the role of U.S. leadership

A roadmap to at-scale CCUS deployment in the U.S.

Options for negative carbon emissions in California

Mar / Apr 2020 Issue 74

ION Clean Energy - a billion tonnes of CO2 by 2050



- CO2 DataShare launches open, digital data sharing portal
- Rice lab turns carbon rich waste into valuable graphene flakes
- BP, Eni, Equinor, Shell and Total form Net Zero Teesside consortium
- CCUS only pathway to achieving net-zero emissions in the cement industry

Bellona report: North European cities aim at zero emissions with CCUS

Together with The Carbon Neutral Cities Alliance (CNCA) NIRAS and five Northern European capitals, Bellona has launched a report, "Cities Aim at Zero Emissions: How carbon capture, storage and utilisation can help cities go carbon neutral"

The report overviews the latest CCS and CCU technologies, the current progress made by the five cities, and business models and viability analytics. Additionally, it reviews the current EU funding opportunities available for cities and develops recommendations for cities interested in implementing these emissions-reducing technologies.

Amsterdam, Copenhagen, Helsinki, Stockholm and Oslo are examining the latest CCS and CCU technologies to go carbon neutral. Though rarely discussed in the cities context, these technologies will be necessary if cities are to live up to the Paris Agreement and achieve their ambitious climate targets.

"In identifying the potential for and barriers to CCSU on a city-scale, this research gives cities a better understanding of how to make decisions related to CCS and CCU technology. To get to carbon neutrality well before 2050, cities need to understand all of the options available and risks associated with them, which this important five-city effort, led by Copenhagen, helps address." said Johanna Partin, Director of CNCA.

Why Cities Are Investing in CCS and CCU

Today, cities account for 75% of global CO_2 emissions and therefore have a huge responsibility related to reducing their climate impact and setting the pathway towards a fossil free society. While many cities are setting ambitious climate targets, it will become difficult to reach carbon neutrality with existing measures and within cities' spheres of influence.

Heidi Sørensen, Director of Climate Agency in Norway mentioned in fact that "Oslo's target to reduce emissions by 95% in 2030 depends on CCS of our waste incineration plant. This report underlines the potential for CCS and CCU in cities and on waste incineration in particular."

The report demonstrates how cities can be infrastructural hubs for new climate technologies and how cities can ensure that new innovations enter the market. The climate leadership of Amsterdam, Copenhagen, Helsinki, Stockholm and Oslo, as an example, is accelerating innovation and increasing clean investment in their cities.

ARC is investigating the possiblity of capturing CO2 from the Amager Bakke waste-to-energy plant in the city of Copenhagen (Photo: Amager Resource Center/Ehrhorn/Hummerston)

Background on CCS and CCU Technology

Carbon capture technologies are not a far-off solution. They're already in operation. Nineteen facilities are currently implemented globally and four more are under construction. They capture and store roughly 25 million tonnes CO_2 annually, and this number is expected to increase to about 40 million tonnes CO_2 annually as new projects come online.

"City cooperation on large-scale CO2 transport and storage infrastructure will bring down costs. It will also create confidence that these cities and regions will remain an attractive long-term location for industry that will face increasingly strict requirements for climate action" concluded Olav Øye, Senior Adviser for CO2 Capture and Storage – The Bellona Foundation.

Lessons Learned, City to City

"Helsinki has learned a great deal about the current situation and experiences of other northern reference cities in CCS/CCU issues. The most important information has been the potential and realism of the various technical solutions and their technological readiness level, which info can be utilized as the city and city-owned energy company seek to achieve carbon neutrality by 2035 through various set of measures" said Esa Nikunen, General Director at City of Helsinki.

Although no perfect recipe exists, this report includes recommendations for public authorities willing to engage with these carbon capture technologies.

The report overviews how the cities are mapping their own emissions; assessing the viability of carbon capture, transport and storage; accessing funding; and using public procurement to establish a first market for clean products.

More information

www.bellona .org

carbonneutralcities.org

www.niras.com

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Front cover:

The conceptual 300 MW CO2 capture island and supporting balance of plant. ION Clean Energy is looking to validate promising CO2 capture economics with a FEED study (pg. 2)

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Leaders - CCUS in the U.S.

Projects and policy

Capture and utilisation

Transport and storage

ION Clean Energy looks to capture one billion tonnes of CO2 by 2050

ION Clean Energy is looking to validate promising CO2 capture economics with a FEED study and has an ambitious plan to capture one billion tonnes of CO2 by 2050.

ION Clean Energy, founded in 2008 with a mission to identify, develop, and commercialize a novel, low-cost carbon dioxide (CO2) capture technology, has recently set a target of capturing one billion tonnes of CO2 by 2050 from large utility and industrial sources.

While this target may seem ambitious, aspirations such as these are critical in order to have a significant impact on global CO2 levels. Many of the largest companies around the world have set aggressive net-zero CO2 targets, and ION stands poised to help them decarbonize their direct and/or indirect emissions from stationary point sources.

ION's ICE-21 Technology Development

ION has demonstrated the application of their technology at increasing developmental scales through multiple U.S. Department of Energy National Energy Technology Laboratory (DOE/NETL) funded programs. This started with a proof-of-principle campaign where they tested on both coal and natural gas-fired flue gas at the University of North Dakota Energy & Environmental Research Center at the 0.05 MWe scale.

In 2015, ION performed parametric and steady-state operations at the National Carbon Capture Center's (NCCC) Pilot Solvent Test Unit, a 0.5 MWe coal-fired post-combustion testing facility located in Wilsonville, Alabama. As a result of the successful test campaign at NCCC, ION continued towards commercialization with a 6-month test campaign at the CO2 Technology Centre Mongstad's (TCM) 12 MWe Amine Plant in Norway.

ION conducted a comprehensive and productive campaign at TCM, totaling 2,750 hours of testing, while capturing over 14,000 tonnes of CO2. Furthermore, the parametric data gathered from the TCM campaign validated the ION process model under various operational settings. Building on the results of these test campaigns and utilizing the validated process model, ION has implemented process improvements that take advantage of their advanced solvent to reduce energy consumption and optimize the system to achieve a low cost of capture. The resulting commercial scale process model predicts a specific reboiler duty less than 2.4 MJ/kg-CO2 (1,060 BTU/lb-CO2).

Figure 1 - The conceptual 300 MW CO2 capture island and supporting balance of plant systems

In addition to lower energy usage, ION's solvent has consistently maintained CO2 capture targets for long operational periods with no indication of accelerated breakdown rates and has demonstrated excellent material compatibility against corrosion coupons of typical materials of construction. Furthermore, ION's solvent outperformed the TCM 2015 baseline with approximately 70% fewer emissions when testing on flue gas from a natural gas source.

The ICE-21 solvent technology builds upon decades-old gas treatment engineering fundamentals which, when combined with the lessons learned and experience gained during the development and demonstration phase, results in a low-risk, solvent-specific optimized process. Based upon independent techno-economic-analyses (TEA) performed by Sargent & Lundy LLC, in which ICE-21 was compared to the Shell Cansolv DOE-BBS base case, ION's system demonstrated more than 20% reduction in the cost of CO2 capture.

	CO_2 Island	Units
Slipstream	300	MWe
EPC Capital Cost	$438,000,000	$
Loan Term	20	years
Interest Rate	7.0%	%
Annualization Factor	0.0944	
Annualized CAPEX	$41,300,000	$/yr
Variable O&M Cost	$19,300,000	$/yr
Fixed O&M Cost	$8,930,000	$/yr
Total OPEX	$28,200,000	$/yr
Total Annual Cost	$69,500,000	$/yr
Total Annual CO_2 Production at 85% CF	1,900,000	tonne/yr
Cost of CO_2 Capture	$36.60	$/tonne

Table 1 – Cost of capture calculations for the pre-FEED study

Capture Costs for 300 MW

ION has recently completed a preliminary Front-End Engineering Design (pre-FEED), targeting the development of an AACE Class 3 cost estimate (-20/+30%), for a 300 MW CO2 Capture facility retrofitted onto an existing coal-fired power station.

The project was supported with funding by DOE/NETL and was performed in collaboration with the host site, Nebraska Public Power District's Gerald Gentleman Station. ION designed the CO2 carbon capture system with support from Koch Modular Process Systems, who produced engineering deliverables and costed the capture equipment. Siemens provided vendor support and designed the compression system utilizing their supersonic compressors, the DATUM-S. Sargent & Lundy LLC (S&L) completed the balance of plant design and engineering for the integration of the carbon capture system with the station. Additionally, S&L compiled all the costing data to generate the CAPEX, OPEX, and cost of capture deliverables.

The engineering design effort incorporated tens of thousands of engineering hours to complete the design tasks that are required to achieve the Class 3 cost estimate. These tasks include generating process design deliverables such as a process flow diagram, process model, heat and mass balances, piping and instrumentation diagrams, equipment specifications, and utility demands.

The balance of plant engineering tasks covered the necessary work for integration of the capture facility (foundational, structural, and architectural design), while also designing the subsystems that supply the necessary steam, electricity, cooling water, and conditioned flue gas. Supplemental studies were investigated by the project team which included identifying quantities and supply of commodities required, review of permitting requirements, a constructability review, and a preliminary hazard and operability study. The conceptual 300 MW CO2 capture island and supporting balance of plant systems is represented in Figure 1.

One of the primary deliverables from the study was the AACE Class 3 Engineering, Procurement and Construction (EPC) cost for the CO2 island and integration, which is $438,000,000. As shown in Table 1, these capital costs are annualized and combined with the operating and maintenance costs to determine the total annual cost of the capture facility required to remove, treat, and compress one tonne of CO2.

A conservative interest rate of 7.0% was used based on interest rates utilized by S&L for this level of study and a financing term of 20 years. The 300 MW facility will capture 1.9 million tonnes of CO2 per year, when utilizing an 85% capacity factor, resulting in a cost of capture for the CO2 island of $36.60/tonne. Applying an interest rate of 4.5%, which is supported by historical rates for previous large capital projects in the power industry, further reduces the cost of capture to $32.50/tonne.

Recent economic analyses of ION's technology places ICE-21 among the lowest cost commercially available CO2 capture solvent technologies in the CO2 capture space. Figure 2 compares ION's levelized cost of capture at commercial scale to both direct air capture and currently operating commercial installations.

As a result of this work, ION has recently been awarded further funding from DOE/NETL to continue developing this project through a FEED study targeting an AACE Class 2 cost estimate. ION will lead the same project team to continue into this new study, at the same generation unit, but will scale-up the capture island to process the full 700 MW of flue gas generated at maximum capacity. The capture facility will be comprised of two 350 MW capture trains and is expected to generate approximately 4.3 million tonnes of CO2 per year at an 85% capacity factor.

Looking to the Future

s a result of the 45Q tax incentives, ION has begun building consortiums of subject matter experts, e.g., engineering, construction, financing, utilization, and sequestration, as ION recognizes that the development of CCUS projects is likely to be complex and time is of the essence in order to achieve the 45Q December 31, 2023 deadline. With the support of these partnerships, ION is currently initiating feasibility studies in order to have multiple projects meet the 45Q deadline.

While control of CO2 emissions has been largely focused on coal-fired power stations, increasing scrutiny is being felt in other sectors of the carbon economy where emitters with lower concentrations of CO2 in their flue gases are surpassing coal-fired emissions in the U.S. on an annual basis. Natural gas fired power, as well as industrial sources, are increasingly becoming more attractive host sites for CCUS given the relatively young age of the facilities as well as the high capacity factors.

ION plans to deploy its technology broadly across these industries, targeting facilities with strategic initiatives to reduce their carbon footprint and/or significant remaining lifetime on their assets. ION will be prioritizing targets based on host plant characteristics as well as proximity to existing CO2 pipelines, local EOR utilization opportunities and/or permanent sequestration sites. In addition, ION is also investigating opportunities for sites who could utilize captured CO2 as a feed stock for chemical and biological processes, many of which represent higher value products than EOR.

Endeavoring to reduce the substantial costs facing many host sites and in order to take advantage of financial incentives such as 45Q, ION has also developed business relationships whereby they can facilitate the financing, ownership and operation of the capture facility, thereby minimizing costs and impact to the CO2 producer. Alfred "Buz" Brown, CEO of ION recently stated: "The introduction of 45Q tax credits creates significant opportunities for large scale, commercial implementation of CO2 capture technologies. Now is the time to launch these efforts and to begin our drive to capture one billion tonnes of CO2 by 2050."

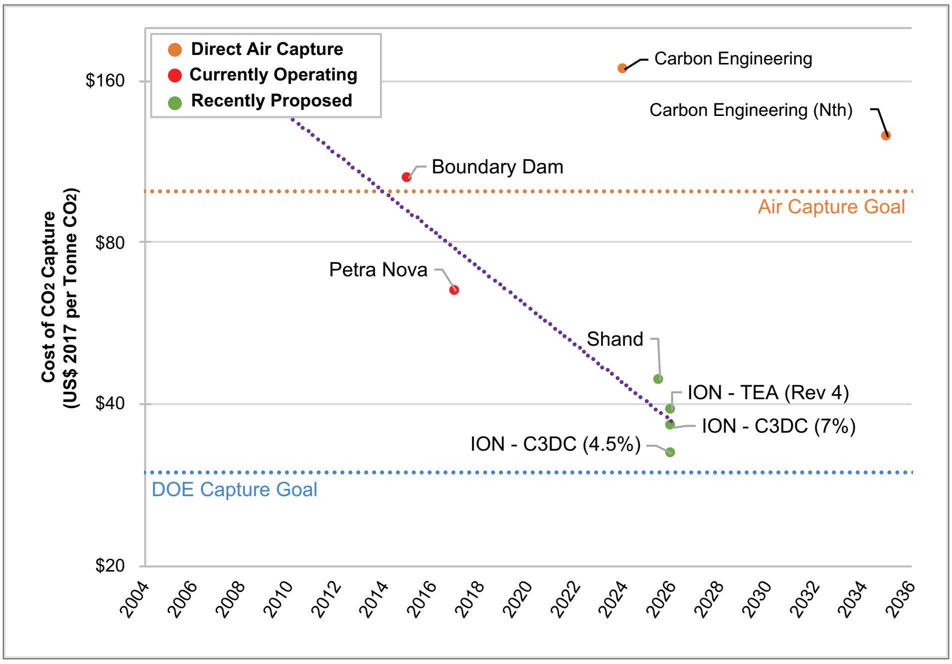


Figure 2 – Cost of capture for direct air capture compared to currently operating and proposed commercial-scale post-combustion capture projects

More information

ioncleanenergy.com

U.S. news

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

svanteinc.com

www.lafargeholcim.com

www.oxy.com

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

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

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

The carbon-capture facility under review will employ Svante's technology to capture carbon directly from industrial sources at half the capital cost of existing solutions. Occidental, the industry leader in CO2 management and storage, would sequester the captured CO2 . Pairing carbon capture from a cement plant with CO2 sequestration is a significant step forward for the cement industry in reducing its carbon footprint.

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

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

This joint initiative follows the recently-launched Project CO2MENT between Svante, LafargeHolcim and Total in Canada at the Lafarge Richmond cement plant, where progress has been made towards re-injecting captured CO2 into concrete.

NETL supported Petra Nova project celebrates three years of sustainable operation

netl.doe.gov

The world's largest operating post-combustion carbon dioxide (CO_2) capture system Petra Nova celebrates its third anniversary Jan. 10, 2020.

The project, supported by the U.S. Department of Energy (DOE) Office of Fossil Energy and administered by NETL, is demonstrating how carbon capture, utilization, and storage technologies can economically support the flexibility and sustainability of fossil fuels at commercial scale.

Owned and operated by NRG Energy Inc. and JX Nippon Oil and Gas Exploration Corporation, Petra Nova is located southwest of Houston Texas and applies carbon capture technology to an existing unit at the coal-fired W.A. Parish Generating Station.

Commencing operation in 2017, the Petra Nova project addresses capture and beneficial reuse of CO_2 from coal-based electricity production. The project uses an advanced amine-based process to capture CO_2, which is then compressed, dried, and transported for enhanced oil recovery (EOR) at the West Ranch Oil Field in Jackson County, Texas, to boost oil production.

Using the Kansai Mitsubishi Carbon Dioxide Recovery (KM-CDR) Process©, the Petra Nova project is designed to capture approximately 90% of the CO_2 from a 240-megawatt equivalent flue gas slipstream — which is approximately 1.6 million tons of CO_2 per year (assuming an 85% availability).

Since beginning operations in January 2017, Petra Nova has captured more than 3.9 million short (U.S.) tons of CO_2 and West Ranch Oil Field has produced more than 4.2 million barrels of oil through EOR.

Petra Nova applies carbon capture technology to an existing unit at the coal-fired W.A. Parish Generating Station (Image: ©NRG Energy)

IRS gives clarity on carbon capture tax credit

www.irs.gov

The Internal Revenue Service has issued initial guidance to help businesses understand how legislation passed in 2018 may benefit those claiming carbon capture credits.

The guidance addresses the definition of "beginning of construction" and provides a safe harbor for partnership allocations of the credit.

After the enactment of the Bipartisan Budget Agreement in February 2018, the IRS issued Notice 2019-32 requesting comments from taxpayers regarding the changes to the carbon capture credit in the new law. After carefully considering the comments, the IRS is issuing guidance to provide clarity, especially regarding the definition of "beginning of construction."

In Notice 2020-12, the IRS provides guidance to help businesses determine when construction has begun on a qualified facility or on carbon capture equipment that may be eligible for the carbon capture credit. This notice provides broad guidance in lieu of taxpayers requesting private letter rulings in this area.

In Revenue Procedure 2020-12, the IRS creates a safe harbor for the allocation rules for carbon capture partnerships similar to the safe harbors developed for partnerships receiving the wind energy production tax credit and the rehabilitation credit. The safe harbor simplifies the application of carbon capture credit rules to partnerships able to claim the credit.

The IRS anticipates issuing further guidance in the near future on issues ranging from secure geological storage to utilization to recapture of the credit for those claiming credits for carbon capture.

NETL infographic highlights advanced manufacturing

www.netl.doe.gov

NETL has released an informative carbon capture infographic that highlights the role of advanced manufacturing in driving down capture costs and how it can improve process performance (see back page).

Additive manufacturing, using 3D printing, enables the development of components for carbon capture equipment that intensify heat and mass transfer, improve process performance and reduce overall equipment size, lowering capital and operating costs.

The Lab manages a vast portfolio of carbon capture research and development projects that are successfully reducing costs to ensure the availability of clean, reliable and affordable energy from America's abundant domestic resources.

In support of these projects, the Lab has published a series of infographics that explains the structure of the Carbon Capture Program, illustrates its impact and highlights the achievements of notable projects.

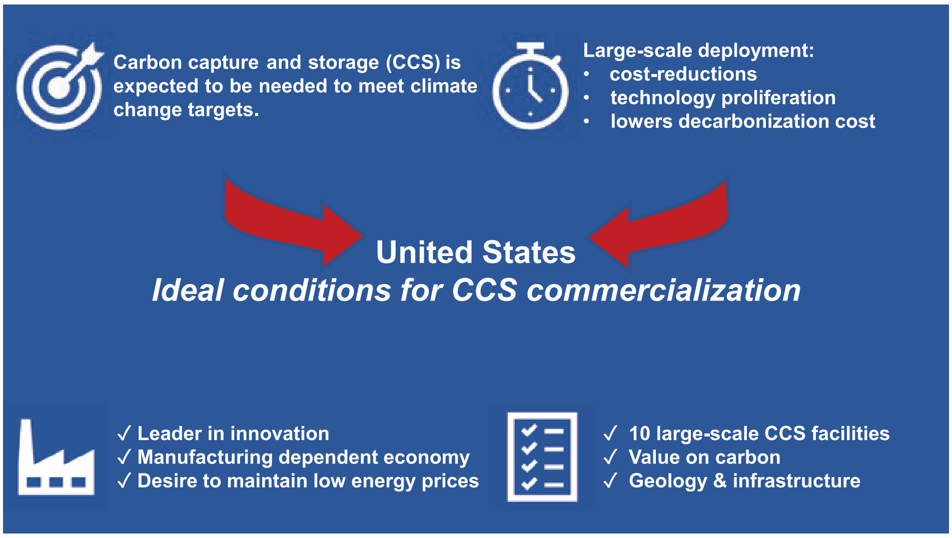
This most recent graphic outlines three projects that are using 3D printing to produce rapid protypes with the potential to capture CO_2 more efficiently and economically.

CCUS: the role of U.S. innovation leadership in commercialisation

A paper by Lee Beck, Senior Advisor for Advocacy and Communications at the Global CCS Institute, concludes that the USA is in a prime position to commercialise CCUS technology.

As of November 2019, more than half of global large-scale CCS facilities are in the USA, thanks to a history of sustained government support for the technologies, says Lee Beck in the paper, "Carbon capture and storage in the USA: the role of US innovation leadership in climate-technology commercialization" published in Clean Energy.

Recently, the USA has seen a raft of new developments on the policy and project side signaling a reinvigorated push to commercialize the technology. Analysing these recent developments using a policy-priorities framework for CCS commercialization developed by the Global CCS Institute, the paper assesses the USA's position to lead large-scale deployment of CCS technologies to commercialization.



It concludes that the USA is in a prime position due to the political economic characteristics of its energy economy, resource wealth and innovation-driven manufacturing sector.

As such, US leadership on the deployment of CCS technologies would make significant contributions to the world reaching its climate and sustainable-development goals.

It would also contribute to reducing the cost of CCS, a technology that is essential to meeting climate goals and enabling technology deployment abroad.

The paper seeks to provide an overview of CCS deployment in the USA while assessing the maturity of the US deployment framework, including policies and infrastructure.

Conclusions

The paper concludes that the USA provides ideal preconditions to commercialize CCS technologies due to its strong dependence on fossil fuels and manufacturing, coupled with an innovation-based economy and a desire and pressure to maintain extremely low energy prices.

However whilst the USA certainly evidences a very advanced policy incentive and infrastructure framework, not least because it also hosts the most facilities globally, conditions for large-scale CCS deployment on the scale necessary to meet climate goals remain incomplete.

The latest movements in terms of policy development in the USA provide a promising outlook, particularly with the implementation of 45Q and further initiatives to address infrastructure shortcomings, access to affordable private capital and storage characterization.

Including CCS in regional carbon markets and transition from renewable- to clean-energy standards can further increase policy support for CCS deployment. Further priorities include an emphasis on project deployment enabling technology optimization through more investment in demonstration projects,

possibly by the government itself. Emphasis should also be placed on reducing risk through government involvement, clarifying liability and regulatory questions, and enabling the build-out of pipelines between emissions clusters and storage hubs and facilities.

Moreover, creative incentive structures to reduce emissions in the industrial sector are needed, as is an innovative business model for CO2 transport and storage.

Finally, if the USA can accelerate the deployment of CCS technologies accelerating the cost-reduction process, similarly to what Germany has done for solar and Great Britain for offshore wind, this would not only reduce the collective-action problem that climate change represents, but also bring the world closer to tackling its global emissions problem.

More information

www.globalccsinstitute.com
academic.oup.com/ce

A roadmap to at-scale deployment of CCUS in the United States

A draft National Petroleum Council report, "Meeting the Dual Challenge: A Roadmap to At-Scale Deployment of Carbon Capture, Use, and Storage" finds that CCUS is essential to meeting the dual challenge of providing affordable, reliable energy while addressing the risks of climate change at the lowest cost.

Secretary of Energy Rick Perry requested the National Petroleum Council's (NPC) advice on actions needed to deploy commercial CCUS technologies at scale into the U.S. energy and industrial marketplace. Achieving this objective will promote economic growth, create domestic jobs, protect the environment, and enhance energy security.

The response to the request required a study that considered technology options and readiness, market dynamics, cross-industry integration and infrastructure, legal and regulatory issues, policy mandates, economics and financing, environmental impact, and public acceptance. The effort involved over 300 participants from diverse backgrounds and organizations, 67% of whom are employed by organizations outside of the oil and natural gas industry.

Technology	R&D (including pilot programs)	Demonstrations	Total	10-Year Total
Capture (including negative emissions technologies)	$500 million/year	$500 million/year	$1.0 billion/year (over 10 years)	$10 billion
Geologic Storage	$400 million/year		$400 million/year (over 10 years)	$4 billion
Nonconventional Storage (including EOR)	$50 million/year		$50 million/year (over 10 years)	$500 million
Use	$50million/year		$50 million/year (over 10 years)	$500 million
Total	**$1.0 billion/year**	**$500 million/year**	**$1.5 billion/year**	**$15 billion**

10 Year RD&D Funding Levels Recommended by NPC Study on CCUS

The Council found in this "Roadmap to At-Scale Deployment of CCUS" that as global economies and populations continue to grow and prosper, the world faces the dual challenge of providing affordable, reliable energy while addressing the risks of climate change. Widespread CCUS deployment is essential to meeting this dual challenge at the lowest cost.

The United States is uniquely positioned as the world leader in CCUS and has substantial capability to drive widespread deployment. The United States currently deploys approximately 80% of the world's carbon dioxide (CO2) capture capacity. However, the 25 million tonnes per annum (Mtpa) of CCUS capacity represents less than 1% of the U.S. CO2 emissions from stationary sources.

The study lays out a pathway through three phases of deployment—activation, expansion, and at-scale—that supports the growth of CCUS over the next 25 years, and details recommendations that enable each phase. In the first phase, clarifying existing tax policy and regulations could double existing U.S. capacity within the next 5 to 7 years. Extending and expanding current policies and developing a durable legal and regulatory framework could enable a second phase of CCUS projects (i.e., 75 to 85 Mtpa) within the next 15 years.

Achieving CCUS deployment at scale (i.e., additional 350 to 400 Mtpa) within the next 25 years, will require substantially increased support driven by national policies. In addition, substantially increased government and private research, development, and demonstration (RD&D) is needed to improve CCUS performance, reduce costs, and advance alternatives beyond currently deployed technology.

Increasing understanding and confidence in CCUS as a safe and reliable technology is essential for public and policy stakeholder support. The oil and natural gas industry is uniquely positioned to lead CCUS deployment due to its relevant expertise, capability, and resources.

Integral to success is adherence to the Council's following recommendations for engaging stakeholders:

• Government, industry, and associated coalitions should design policy and public engagement opportunities to facilitate open discussion, simplify terminology, and build confidence that CCUS is a safe and secure means of managing emissions.

• The oil and natural gas industry should remain committed to improving its environmental performance and the continued development of environmental safeguards.

• Commensurate with the level of policy enactment being recommended, the oil and natural gas industry should continue its investment in CCUS.

More information

www.npc.org

Projects study CO2 geological storage

Virginia Tech scientists are working on two nationally funded projects to study CO2 geological storage.
www.mining.vt.edu

With separate grants from the National Science Foundation and the National Energy Technology Laboratory, Cheng Chen, an assistant professor of mining and minerals engineering in the Virginia Tech College of Engineering, is studying the capacity to store CO2 in underground geologic formations.

Chen offers an innovative approach for examining how gas can be injected into subsurface geological formations for long-term storage.

DoE's NETL grant: Machine-learning based model

Chen was awarded $480,000 from the Department of Energy's National Energy Technology Laboratory's University Coalition for Fossil Energy Research Program. The two-year project seeks to develop a machine-learning-based, scale-bridging, data assimilation framework with applications to geologic carbon sequestration.

Chen and his team will work to develop a less time-consuming approach to analyzing the permeability of geologic rock formations, which is based on large amounts of visualization data, such as that of CT scans. This analysis is critical to understanding a rock's permeability and its effect on carbon dioxide injection.

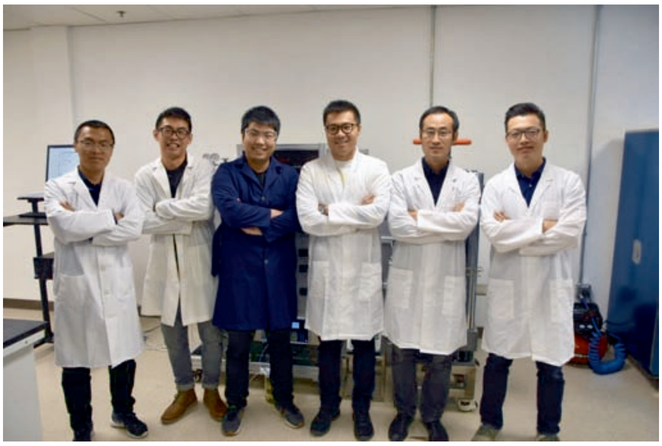
Normally, this data is analyzed with computer modeling, but it can be slow and time-consuming, Chen explained. The objective of a machine-learning based approach is to collect only a specified quantity of sample data.

"Once there is enough mapping between the rock geometry and the fluid mechanics properties of the rock, a model can be trained to predict the fluid mechanics properties of new samples," said Chen.

Researchers will collect image data from associate professor of mining and mineral engineering Nino Ripepi's field scale injection site, then develop a number of machine-learning models to analyze that data.

National Science Foundation Grant: Convection in porous media

The National Science Foundation also awarded Chen with a $368,000 grant from the Division of Earth Sciences to study the fundamentals of miscible density-driven convection in porous media, which is encountered in geologic carbon sequestration.



Members of the Chen Lab Research Group (left to right): Weiyu Zheng, Yuntian Teng, Zihao Li, Patrick Fan, Ruichang Guo, and Cheng Chen (Image: ©Virginia Tech)

This project entails laboratory experiments in which researchers will control and study the process of miscible density-driven convection. A possible means for storing carbon dioxide is by injecting it into deep saline aquifers. Once injected, the carbon dioxide is in a supercritical state — somewhere between a gas and a liquid. Over a period of 10 to 100 years, the gas begins to dissolve into the water.

"The pore water near the top cap rock of the aquifer is saturated with dissolved carbon dioxide and thus is denser than the underlying water not saturated with carbon dioxide, which can therefore cause miscible density-driven downward convection," Chen said.

According to Chen, the process effectively improves the long-term security of geological carbon dioxide storage. The miscible density-driven downward convection transports dissolved carbon dioxide away from the cap rock and reduces the risk of the gas leaking at the cap rock. It also has the potential to enhance subsequent carbon dioxide dissolution from the supercritical phase into the aqueous phase.

Salinity of underground aquifers affects the convection of CO2. Chen's approach is novel in that it seeks to design well-controlled laboratory testing methods for testing the process and numerous models used to understand it.

Chen and his team will improve existing numerical models by carrying out simulations and lab experiments to confirm their hypothetical models and construct a porous media replica, or analog model. "The analog model enables us to control permeability distribution and porous media, while its glass panel construction enables the flow of the dyed fluid to be observed and recorded with a high-speed camera," he said.

Chen is working with co-principal investigators Yang Liu, associate professor in mechanical engineering's nuclear energy program; Heng Xiao, assistant professor of aerospace and ocean engineering; James McClure, computational scientist at Virginia Tech's Advanced Research Computing Center; Ripepi; and engineering graduate students.

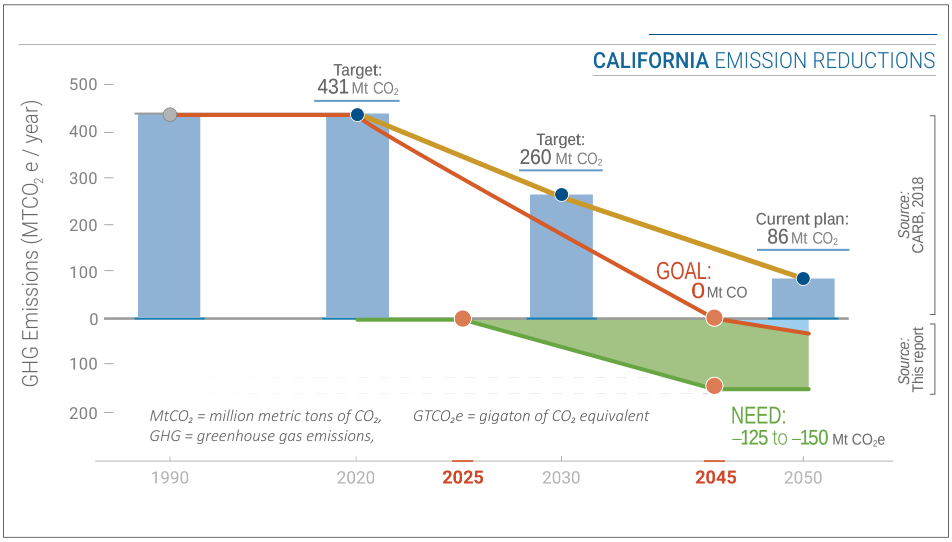
"Geological sequestration is perhaps the only viable technology to mitigate global climate change while continuing large-scale use of fossil energy," Chen said. "If, as a society, we still depend on fossil fuels in the foreseeable future, our understanding of density-driven convection in porous media and the ability to better predict and model the fluid mechanics of deep saline aquifers might allow us to safely reduce or even eliminate greenhouse gasses from the atmosphere."

Report outlines ways California could become carbon neutral by 2045

Lawrence Livermore National Laboratory (LLNL) scientists have identified a robust suite of technologies to help California become carbon neutral – and ultimately carbon negative – by 2045.

The study, "Getting to Neutral: Options for Negative Carbon Emissions in California," was conducted as part of LLNL's expansive energy programs work and the Laboratory's Carbon Initiative. The goal of the initiative is to identify solutions to enable global-scale CO2 removal from the atmosphere and hit global temperature targets.

The report details a thorough assessment of the advanced carbon reduction technologies now available, their costs, as well as the trade-offs necessary to reach the state's decarbonization goal. The report codifies a number of significant conclusions by researchers at eight institutions. It serves as a resource for policymakers, government, academia and industry.



Goals of California's emissions plan extrapolated to 2045 (CARB, 2017) with negative emissions estimates from the report

California executive order B-55-18 mandates that the state achieve carbon neutrality by 2045 and maintain net negative emissions thereafter. Achieving this goal would complete a chain of other ambitious statewide targets for reducing greenhouse gas emissions.

The LLNL study finds that, not only is carbon neutrality possible, but that California can once again be a global climate leader by demonstrating how to remove significant amounts of CO2 from the atmosphere.

"Our findings give us confidence that this combination of negative emissions technologies and the state's existing ambitions put the finish line in reach for California," said Roger Aines, LLNL's Energy Program chief scientist and the lead on the project.

"The report's findings also indicate we could become carbon neutral sooner than anticipated, at a cost less than expected, while boosting California's economy and creating quality jobs in areas such as the Central Valley. Important co-benefits to air quality and wildfire prevention also will bring welcome relief to our state."

Carbon neutrality refers to achieving net-zero carbon dioxide emissions by balancing any remaining atmospheric emissions with removal of carbon dioxide from the air, or simply by eliminating carbon emissions altogether. It applies to everything that generates greenhouse gases.

In the report, funded by the Livermore Lab Foundation (LLF) with grant support from the ClimateWorks Foundation, LLNL focused on three specific pillars of negative emissions: natural and working lands, carbon capture from waste biomass utilization and direct air capture.

The team identified a portfolio of approaches for achieving greater than 125 million tons per year of negative emissions for California by 2045 and evaluated the scope of state and private investment to best achieve the goal.

"Without CO2 removal, reaching our carbon neutrality goal will be slower, more difficult and costly," said LLNL chemist Sarah Baker, lead author of the report. "While there are no silver bullets, we have evaluated strategies that rely on many existing technologies and resources, creating a CO2 removal blueprint that can be replicated."

"Climate change is the defining issue of our time. From shifting weather patterns that threaten food production to rising sea levels that increase the risk of catastrophic flooding, the impacts of climate change are global and unprecedented," said Dona Crawford, Livermore Lab Foundation board chair.

"We are grateful and proud to have worked with the ClimateWorks Foundation to support this important research and we hope it will serve as a defining guide for action."

More information
www.llnl.gov

NETL project validates geologic storage of CO2

The carbon footprint created by industry and other human activity in Big Sky Country — the area stretching across the Great Plains and into Canada — can be reduced using technology pioneered by NETL and partners at a leading research university.

Work completed as part of the NETL-backed Plains CO2 Reduction (PCOR) Partnership demonstrates not only the ability to reduce carbon dioxide emissions, it also enhances the efficiency of oil production, an important consideration to bolster domestic energy production.

PCOR is one of the U.S. Department of Energy's (DOE) seven Regional Carbon Sequestration Partnerships (RCSPs), which have been laying the groundwork since 2003 for large-scale geologic storage of CO2 in the United States as a means of mitigating effects of climate change while still allowing for the efficient and affordable use of fossil fuels for energy production.

RCSP activities, supported by NETL, have included assessments of geologic and terrestrial storage potential in each region, followed by small-scale validation tests and six large-scale (greater than 1 million metric tons) geologic storage field experiments.

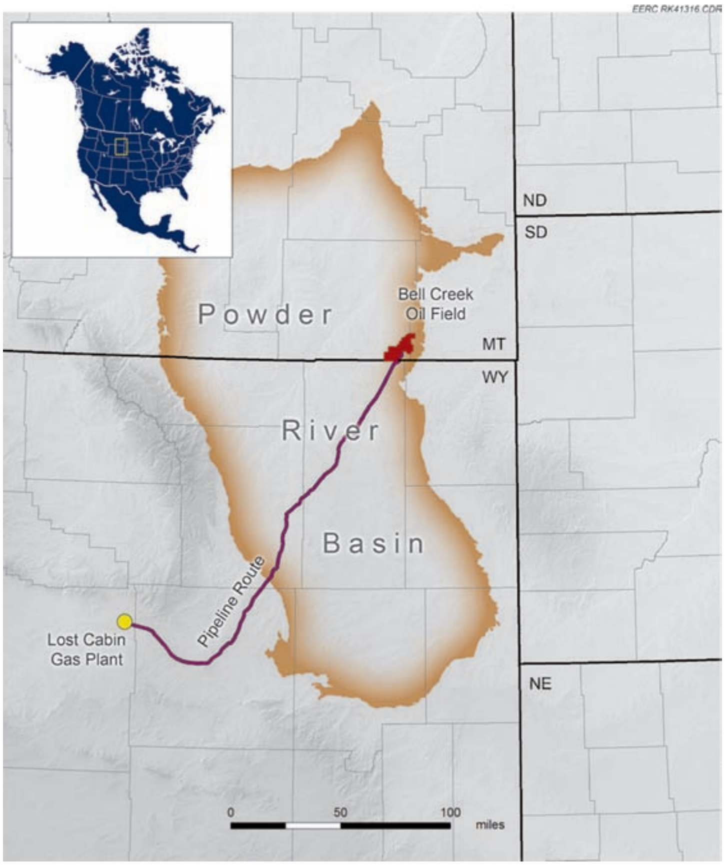
The Energy and Environmental Research Center (EERC) at the University of North Dakota leads the PCOR Partnership. Throughout its history, PCOR has engaged a membership of more than 120 partner organizations drawn from industry, government and research institutions to foster carbon capture, utilization, and storage (CCUS) deployment across a vast region.

The positive environmental impact of PCOR is significant. Stretching from Missouri through the northern Great Plains to north-central Canada, this region possesses outstanding potential for widespread CCUS deployment because it has significant geologic storage resources and an extensive fossil fuel-based industry.

Furthermore, several active CCUS projects in the region are already setting an example for future work by demonstrating safe and effective carbon management strategies with attendant economic benefits.

Another key achievement of the PCOR Partnership was its assessment and monitoring of more than 6 million metric tons of CO2 storage associated with the enhanced oil recovery (EOR) operations, which inject captured CO2 into oil reservoirs to increase production, at Denbury Resources' Bell Creek oilfield in southeast Montana.

At the oilfield, EERC scientists deployed a wide variety of traditional and novel monitoring technologies and assessed their relative strengths and limitations.



Industrial CO2 travels from the Lost Cabin Gas Plant to Bell Creek oil field via pipeline

Through a combination of techniques, the scientists were able to reliably track the location of the injected CO2 within the oilfield, which inspires confidence in the future ability to permanently and safely store large quantities of anthropogenic CO2 from industrial operations. Other advantages of storing CO2 in EOR operations are the ability to extract oil that could not otherwise be obtained and reduce the overall carbon footprint of the oilfield operation.

In addition to the work at Bell Creek, EERC and its partners have provided important scientific and technical support to other large-scale CCUS efforts in the PCOR region, such as the Boundary Dam/Aquistore projects in Saskatchewan and the CarbonSAFE efforts in North Dakota, Wyoming and Nebraska.

More information
www.netl.doe.gov

Projects and policy news

Drax establishes partnerships for negative emissions technology

oilandgasclimateinitiative.com

www.cleanenergyministerial.org

Drax has announced new partnerships with Econic Technologies and Deep Branch Biotechnology.

Drax has announced a new partnership with cleantech company Econic Technologies to explore the potential for using captured carbon dioxide from its biomass power generation to displace oil in the production of plastic products, using its pioneering catalyst technology.

The partnership marks a major step towards enabling other businesses, including in the automotive, consumer and construction sectors, to produce more sustainable polyurethane products. Econic's catalyst technology could save as much as the equivalent of four million petrol cars' worth of CO2 per year in this first market alone.

A new pilot plant has also been installed at the power station in North Yorkshire, by Deep Branch Biotechnology to explore the feasibility of using Drax's CO2 emissions to make proteins for sustainable animal feed products – technology which could enable the agricultural sector to decarbonise.

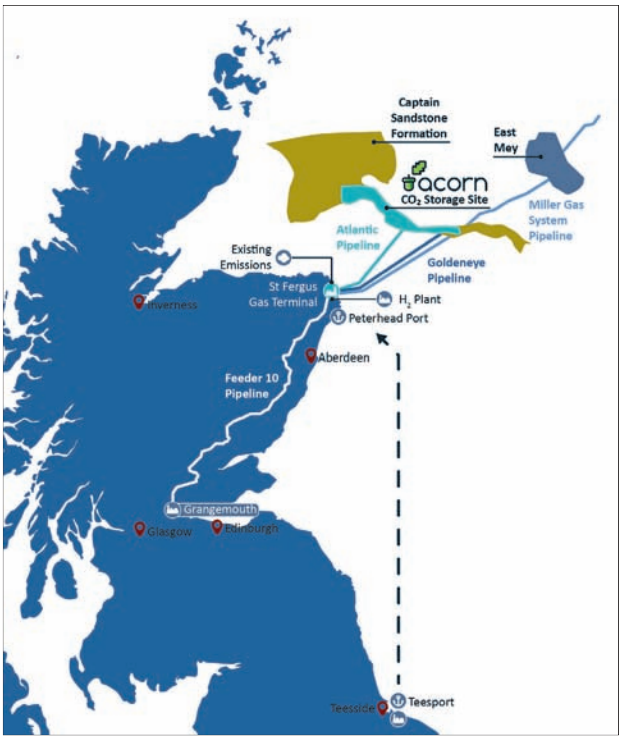
The Rt Hon Kwasi Kwarteng MP, UK Minister of State for Business, Energy and Clean Growth visited the CCUS Incubation Hub at Drax Power Station, to see for himself the pioneering work taking place.

Drax was the first company in the world to announce an ambition to be carbon negative by 2030 when CEO Will Gardiner spoke at COP 25 in Madrid. By applying BECCS technology to its biomass generating units Drax would remove more carbon dioxide from the atmosphere than it produces across the whole of its operations, creating a negative carbon footprint for the company.

Will Gardiner, Drax Group CEO said, "Drax's ambition is to be carbon negative by 2030. Having pioneered the use of sustainable biomass, Drax now produces 12% of the UK's renewable electricity. With the right negative emissions policy for BECCS, we can do much more, removing millions of tonnes of emissions from the atmosphere each year."

"By working with innovative tech companies like Econic and Deep Branch Biotechnology, we are exploring new opportunities for clean growth, which could be critical not only for beating the climate crisis, but also in enabling a just transition, protecting jobs across the North – delivering for the economy and the environment."

Econic Technologies will test the CO2 being captured from Drax's successful one tonne a day BECCS pilot at its own industrial pilot facility, to assess its suitability for producing polymers used in polyurethane plastics.



The CO2 emissions that are created from converting natural gas to hydrogen at St Fergus will all be captured and permanently stored offshore as part of the Acorn project

Acorn project awarded UK Government hydrogen funding

pale-blu.com/acorn

The award of £2.7 million will support 13 months of engineering studies, to progress the technical and commercial plans for the Acorn Hydrogen project at the St Fergus gas terminal.

Pale Blue Dot Energy, the project developer behind Acorn CCS and Acorn Hydrogen was awarded funds from the UK Government's Hydrogen Supply Competition Phase 2.

This first phase of Acorn Hydrogen will establish the technology to convert some of the natural gas at the St Fergus gas terminal in North East Scotland into hydrogen – a clean burning fuel.

The CO2 emissions that are created from converting natural gas to hydrogen at St Fergus will all be captured and permanently stored using the Acorn carbon capture and storage (CCS) infrastructure that is on track to be operating at St Fergus from 2024.

Sam Gomersall, Pale Blue Dot Energy Commercial Director said, "Acorn Hydrogen is a hugely exciting project that is a critical step for Scotland and the UK to reach its ambitious climate change targets. We are working extremely hard, alongside our project study partners: Chrysaor, Shell and Total, to progress this important component of the wider Acorn initiatives, in the aim that Acorn Hydrogen's first injection of hydrogen into the gas grid is in 2025."

"Blending as little as 2% hydrogen into the National Transmission System would remove 400,000 tonnes of CO2 per year from the energy system, and that is just the starting point with an ambition to decarbonise all the natural gas flowing through St Fergus."

Detailed design work on Acorn CCS is already underway, and with this earlier stage design on the first phase of Acorn Hydrogen now started, Acorn is on track to establish critical infrastructure in the mid-2020s ahead of then significantly expanding both Acorn CCS and Acorn Hydrogen, delivering a serious contribution to UK and Scottish Net Zero targets.

CCUS only pathway to achieving net-zero emissions in the global cement industry

With cement demand predicted to rise, carbon capture is an essential technology that can achieve the goal of net zero emissions. By Ian Riley and Manon Burbidge, World Cement Association

It is widely recognised that the cement industry is one of the key contributors to global CO_2 emissions, due to the scale of global cement production, as well as carbon dioxide emissions being inherent to the production process.

Scope 1 emissions, defined by the Greenhouse Gas Protocol as direct emissions created by an organisation's activities, make up about 90% of the industry's CO_2 output. This is mainly due to the fuel used to heat the cement kilns, and the limestone feedstock, calcium carbonate, which breaks down to form carbon monoxide and carbon dioxide.

To combat the scale of the industry's emissions, several steps have been taken over the past 30 years. New technologies have improved average energy efficiency in plants by about 30%, and there has been an increase in alternative fuels, such as municipal wastes, replacing fossil fuels.

The adoption of blended cements has also helped reduced average clinker use per ton of cement and hence the emissions produced from the breakdown of limestone.

Despite this progress, analyses by both cement and non-industry experts have concluded that there is no path to net-zero emissions that does not include carbon capture, usage and storage (CCUS).

Although there are alternatives to concrete for some applications, the material will continue to be necessary for the construction of core infrastructure, such as metro networks, dams and bridges, for the foreseeable future. Indeed, ongoing global urbanisation will mean that cement demand is likely to continue to grow until at least 2050.

Where we are today

To date, the development of CCUS has not received the large-scale investment required to generate rapid progress. While carbon capture is a proven technology, it is still expensive to use and unlikely to progress without strong policies and regulatory incentives. In addition, carbon storage is both high-cost and geographically limited, whilst most carbon usage applications are still in the early stages of development.

There are, however, a handful of current technologies and pilots in the CCUS sphere that show particular promise for use in the cement industry.

CO2 storage vessels, and a lorry being loaded with liquid CO2 for transport to the usage endpoint at the Conch Wuhu CCUS facility in China. The Baimashan Cement Factory in Wuhu uses amine technology to capture CO2 from its cement kiln

Carbon Capture

There are two widely used processes to capture CO_2. The first is post-combustion capture which uses CO_2 absorption reactors, whereby exhaust gases are mixed with a solution that absorbs and removes the carbon dioxide.

The second is pre-combustion gasification, where CO_2 is removed using gasification processes. Feedstock is partially oxidised in steam and oxygen at high temperatures and pressures to form synthesis gas (a mixture of hydrogen, carbon monoxide, carbon dioxide and others). This is usually done using a fluidised bed, which suspends the fuel while flue gas and steam are introduced at the base of the reactor.

Conch Wuhu, one of Conch China's cement plants, piloted a carbon capture project in 2018 to demonstrate that post-combustion capture technology can be used in a cement plant, with its relatively low concentration of CO2 in the flue gas.

This captured 50,000 tons of CO2 over the timescale of the pilot, or 0.5% of the plant's total emissions. The captured gas was sold to carbonated drinks manufacturers and for use in agricultural greenhouses. Although technologically this project was a success, low demand made it difficult to sell even the small proportion of CO2 captured, which has limited future scale-up possibilities.

A different approach to carbon capture is being pioneered at the LEILAC Project in Lixhe, Belgium, using technology engineered by Calix Global. The aim is to capture the process emissions from cement production by re-engineering the process flows of a traditional calciner, heating the limestone indirectly in a steel vessel. This enables the capture of pure CO2 and requires no chemical reagents or additional concentration processes.

Carbon Storage

Carbon sequestration involves placing anthropogenic CO2 emissions in underground geological formations for permanent storage. For successful storage, this process requires deep, porous layers of rock, capped by several layers of impermeable rock.

Depleted oil and gas reservoirs and deep saline aquifers are typically used, so this practice is only possible in areas with suitable conditions and hence not equally applicable or economically viable globally.

The North Sea is an example of a suitable location for CO2 storage, due to its geology and the existing infrastructure from a mature oil and gas industry in the region. Norcem, in collaboration with Heidelberg Cement, is piloting a project that takes advantage of this by implementing the industry's first CCS facility at its Brevik plant in Norway.

The post-combustion CO2 capture technology will allow for 400,000t of CO2 to be captured per year, representing approximately 50% of the plant's emissions. This will then be transported by pipeline and injected into underground reservoirs beneath the North Sea.

Carbon Usage

Carbon dioxide has many uses, including in chemicals, polymers, fertilisers, and synthetic fuels, as well as carbon curing of special concrete and aggregates. However, according to the Carbon Capture Institute, even the most mature technologies are currently only in demonstration phases, with fertilisers and enhanced oil recovery constituting the largest markets.

One area which could be particularly promising for the cement industry is new technology being developed that enables CO2 to be used in building materials.

WCA member Solidia has developed a low-lime, low-energy cement that is currently being produced by LafargeHolcim. In addition to reducing both process and thermal CO2 emissions at the cement kiln, this cement rapidly carbonates when exposed to CO2.

Mineral CO2 sequestration is a naturally occurring process, whereby compounds present in the earth's crust react with atmospheric CO2 to form stable carbonates, such as calcium carbonate (limestone).

The ubiquitous presence of calcium, magnesium and iron in the earth's crust offers the potential for mineral CO2 sequestration to rival the physical storage of CO2 in geological formations, and thus play a major role in reducing atmospheric CO2 levels.

When you take into account emissions at the cement kiln and CO2 consumed during carbonation, Solidia's cement offers a 60% reduction in carbon footprint compared with ordinary Portland cement. The new cement has been used in precast applications in the USA, Canada and the UK, and in ready-mix applications in the USA.

California-based company Blue Planet has developed technology to obtain CO2 from any emission source without the need for concentration or purification. A pilot plant due to start operation this year will take CO2 directly from the flue gas of a natural gas power plant at very low concentration.

The CO2 is then reacted with calcium oxide, derived from demolition waste or industrial by-products, to produce synthetic aggregates which are 40% CO2 by weight.

Similarly, in the UK Carbon8 Systems has developed an accelerated carbonation technology process to react CO2 with calcium and magnesium salts in industrial thermal residues to form solid carbonates, which produce low density synthetic aggregates.

Barriers to CCUS

Current barriers to CCUS are primarily economic: implementing this at scale generally requires government subsidies, with CO2 used for enhanced oil recovery being the only viable business case at present.

The EU CEMCAP project (part of Horizon 2020) has suggested that CCUS processes may add 90% to the cost of cement production, with other estimates being even higher.

Recent announcements by Principles for Responsible Investment, as well as several other investment analysts, suggest that future carbon pricing policies may have a substantial impact on both the cost of cement and the market capitalisations of cement producers.

Worldwide, 85% of CO2 emissions are currently unpriced, and therefore there is little incentive for companies to invest in CCUS. Carbon pricing will need to recognise the additional operating cost of CCUS before we can expect large scale investment from the industry.

Some pioneers, such as WCA member Dalmia Cement, have set the goal of being carbon negative by 2040; their roadmap to achieving this includes carbon capture, utilisation and carbon sequestration. Nevertheless, they are still more the exception than the rule.

In the meantime, through sharing best practices, WCA supports its members in taking the steps they can today to reduce their emissions, by improving energy efficiency, utilising alternative fuels and optimising the use of cementitious materials in their operations.

More information

www.worldcementassociation.org

Atkins report calls for energy 'sea change' to achieve UK Net Zero

The government's Net Zero 2050 target won't be achieved without substantial changes to the UK's energy mix including an urgent boost to CCS.

Engineering Net Zero highlights the major challenges of creating significant capacity in carbon capture and storage, nuclear, wind and hydrogen energy generation. It examines how policy makers and industry need to urgently resolve a number of technical and commercial challenges associated with decarbonising the economy. To achieve Net Zero the UK needs a four-fold increase in low carbon energy - from 155TWh in 2017 to 645TWh in 2050.

The report brings Atkins' experience of delivering the world's largest, most complex infrastructure programmes to bear on this most critical of technical challenges – how to avert the most devastating implications of climate change. It analyses how current capacity and UK policy points away from a reliance on nuclear energy, despite its proven ability to produce low carbon solutions.

Current government policy curtails nuclear in the mid-2030s after completion of the three plants currently in active development.

Alongside this commitment, carbon capture and storage (CCS) capacity is needed to capture, transport and store up to 176 Metric tons of carbon dioxide by 2050 to deliver the Net Zero target. The UK's current capacity for CCS is negligible and needs urgent attention.

CCS is critical to the Net Zero scenario due to a continued reliance on CCGT as part of the generationmix, as well as the use of steam meathane reforming for hydrogen production.

The Net Zero scenario requires the UK to have 40% of UK's energy dependent on CCS. That equates to an equivalent volume of CO2 that is four times the current global CCS capacity by 2050. The UK currently has no CCS industry and no firm plan in place to deliver this.

Speaking about the new report, Chris Ball, Managing Director for Nuclear and Power at Atkins, said: "The green future we aspire to is possible. However, it requires a sea change in how we approach our energy system and the scale of investment required. Government has set the target and working in collaboration with industry and academia we can meet the ambition. But it requires an unprecedented level of commitment, investment and co-ordination to drive forward a programme of works.

"The concern for the UK is that years of only short-term political ambitions have blocked some urgent investments and actions needed to drive forward Net Zero solutions. As we look to 2020, and the UK's new government takes shape, we need tangible investment in testing engineering solutions to our most pressing challenges.

"We welcome today's Queen's Speech with the Government's commitments to increase offshore wind capacity and invest in building a Carbon Capture Storage cluster."

"However, to really prioritise the Net Zero target, we would like to see the Government introduce 'Net Zero Champion' or even a dedicated department with the powers to make the large-scale energy and infrastructure decisions the UK urgently needs."

Atkins views COP26 in Glasgow as an important moment in the Government's path to laying realistic foundations to achieve the critical Net Zero legal requirement.

Over the coming months, the company will be adding to its Engineering Net Zero report to include analysis on the infrastructure and transportation sectors to give policy makers a holistic view of the challenges facing the UK.

Recommendations

1. Early build projects for all recommended energy sources. This process will reduce construction time, enabling delivery at the lowest cost and minimising bills for the consumer.

2. Increased focus and investment in nuclear: urgently prioritise Government consultation on alternative financing models (RAB) for nuclear and develop innovative approaches to construction risk. Reviewing the electricity market and evaluating the impact of intermittent renewables on firm power pricing.

3. Expedite and fund pilot carbon capture and storage projects as quickly as possible.

4. Addressing the 'hidden costs' of system balancing and stability in offshore wind, developing UK floating wind technology and IP, and increased UK supply content.

5. Accelerating the current hydrogen research programme, with a minimum of two demonstration projects.

6. Ensuring the energy storage debate is grounded in current technology. It should be clearly structured on both the power achievable (MW to GW) and how much energy is stored (MWh).

More information

Read the report:

www.atkinsglobal.com

BP, Eni, Equinor, Shell and Total form Net Zero Teesside consortium

BP, Eni, Equinor, Shell and Total assume leadership of the Net Zero Teesside project, with BP as operator, transitioning the project from OGCI Climate Investments.

OGCI Climate Investments – the $1B+ investment fund of The Oil and Gas Climate Initiative – has announced the formation of a consortium of OGCI members – BP, Eni, Equinor, Shell and Total, with BP as operator – to accelerate the development of the Net Zero Teesside project, previously known as the Clean Gas Project.

The partners bring global experience of carbon capture, utilisation and storage technology and are committed to working closely with the UK government and local stakeholders, including the Tees Valley Mayor and Combined Authority, to develop the Net Zero Teesside project to deliver the UK's first zero carbon cluster. With the right government support the project has an ambitious yet achievable potential start-up date of the mid-2020s.

The project will decarbonise local industry by building a transportation and storage system to gather industrial CO2, compress it and store it safely in a reservoir under the North Sea. The transportation and storage infrastructure will encourage new investment in the region from industries that wish to store or use CO2. In addition, a combined cycle gas turbine (CCGT) facility with carbon capture technology will provide low carbon power as a complement to renewable energy sources and underpin the investment in the infrastructure.

Pratima Rangarajan, CEO of OGCI Climate Investments, said, "Net Zero Teesside is a demonstration of OGCI's commitment to accelerating CCUS on a global scale. It's the anchor project, first ideated at the UK Energy Technologies Institute (ETI), developed into an industrial carbon cluster within OGCI Climate Investments and now, the first hub within OGCI's CCUS Kickstarter initiative. This transfer of ownership to the OGCI consortium is proof of how OGCI's initiative is successfully supporting emerging hubs."

Net Zero Teesside also announced at its official launch event in Middlesbrough that it has signed memorandums of understanding (MoUs) with 3 existing industrial partners demonstrating the strong local commitment to decarbonising existing local industry. The MOUs support the continued engagement between the parties in evaluating the technical and commercial case for capture of CO2 from the industrial plant for safe storage.

Attendees at the event including MPs, policy makers, business leaders and local stakeholders will hear from speakers about the significant role Net Zero Teesside will play in helping the UK reach its net zero 2050 greenhouse gas emissions target whilst delivering an annual gross benefit of up to £450 million for the Teesside region and the support of up to 5,500 direct jobs.

Net Zero Teesside would be the first major development to be based on the South Tees Development Corporation site. The launch event today comes just days after the Tees Valley Mayor struck a landmark deal to secure the land at the former SSI steelworks site and bring it back into public ownership, ready for future redevelopment.

Andy Lane, Managing Director of Net Zero Teesside, commented, "Its advantageous location, advanced planning stage, the expertise of our world class project partners and government support for decarbonisation in the UK mean Net Zero Teesside is uniquely positioned to become the UK's first decarbonised cluster. The formation of such a powerful partnership led by BP demonstrates the industry's commitment to the UK government's net zero targets. We're hugely excited to see Teesside back at the forefront of UK industry and want the project to progress further."

Ben Houchen, Tees Valley Mayor, added, "Net Zero Teesside represents the next step in our ambitions for Teesside, Darlington and Hartlepool to become a pioneer in clean energy, driving almost half a billion pounds into the regional economy and boosting the wider UK by £3.2billion."

"This world-leading industrial-scale decarbonisation project will safeguard and create 5,500 good quality, well paid jobs for local people. It will act as a beacon for new technologies and further investment as other companies are attracted to our area, while helping the UK achieve its clean energy potential."

More information

www.netzeroteesside.co.uk

www.oilandgasclimateinitiative.com

Capture and utilisation news

New method converts carbon dioxide to methane at low temperatures

www.waseda.jp

A new method developed by a team of Waseda University scientists led by Professor Yasushi Sekine may contribute to reducing the use of fossil fuels.

The conversion of carbon dioxide to valuable chemicals such as methane has drawn great attention for use in supporting carbon capture and utilization. Especially, methane can be used not only as fuel but also as a hydrogen carrier, transporting town gas to existing infrastructure. For instance, some plants in Germany have already been launched based on the Power to Gas concept, which allows energy from electricity to be stored and transported in the form of compressed gas.

"To recycle carbon dioxide into methane, an established industrial method involves the reaction of hydrogen and carbon dioxide using a ruthenium-based catalyst at temperatures of 300 to 400 degrees Celsius, but this method limited how much and when methane could be produced since it requires such high temperature," Sekine says.

"Additionally, operation at low temperatures was demonstrated to be favorable to improve carbon dioxide conversion and increase the amount of methane produced."

In this newly-developed method reported in Chemistry Letters, carbon dioxide can be converted into methane more efficiently and quickly in the 100 degrees Celsius range.

"This method involves a reaction of nanoparticles called cerium oxide with carbon dioxide in presence of ruthenium catalyst with an electric field," explains Sekine. "The results show that the catalyst exhibited high and stable catalytic activity for converting carbon dioxide to methane through hydrogenation with the electric field."

With this novel method, methane could be produced from carbon dioxide collected from the atmosphere, possibly enabling an unlimited amount of methane production by recycling carbon dioxide from the atmosphere released from factories into valuable energy resources.

Svante and Climeworks collaborate on CCS technology development

www.svanteinc.com

www.climeworks.com

Svante (formerly Inventys) and Climeworks have signed an agreement to collaborate on the development of carbon capture technology solutions to enable customers to transition to a net-zero-emissions future.

Svante offers companies in industries with unavoidable emissions, such as concrete and steelmaking, a commercially viable way to capture large-scale CO2 emissions from existing infrastructure at half the capital cost of traditional solutions. Climeworks offers the worldwide first commercial Direct Air Capture (DAC) solutions to remove CO2 from the atmosphere.

By capturing CO2 from air, DAC solutions can unlock a climate-positive future. By working together, the two companies can accelerate the development and adoption of both technologies for customers across industries and applications.

The Joint Development Agreement (JDA) will enable Svante's and Climeworks' respective carbon capture technology solutions to be scaled-up faster and effect a transition to a net-zero-emissions future sooner. The combination of Climeworks' revolutionary DAC solutions with Svante's source capture technology will support further development of climate-positive carbon solutions for both carbon removal and industries with unavoidable emissions.

"We strive to deliver the world's most robust and scalable DAC solutions," said Christoph Gebald, the Climeworks co-founder. "By combining our cutting-edge DAC solution with Svante's filter technology, we create a potentially game changing DAC solution."

"Climeworks is an ideal partner for a large-scale rollout of market-ready technology to provide a zero-CO2 emission solution. Climeworks' and Svante's cost advantage, combined with progressive policies like the United States' 45Q tax credit and the Low Carbon Fuel Standard (LCSF) credits, can make carbon capture and removal profitable across a range of large-scale industrial applications." said Claude Letourneau, Svante's President and CEO.

Further potential benefits include the use of waste heat from Svante's industrial carbon capture system for Climeworks' direct air capture process.

Liquid Wind secures EU funding for CO2 to fuel technology

www.liquidwind.se

The company will convert waste carbon dioxide (using carbon capture) and renewable electricity into renewable liquid fuel, e-methanol, providing a viable and cost-effective alternative to fossil-origin fuels particularly for shipping vessels and heavy transport.

International Shipping contributes more than 1 billion tons to global GHG emissions and the International Marine Organisation (IMO) has committed to reducing emissions by 50% by 2050. The Cruise Line industry has even stronger ambitions, with a 40% reduction by 2030. However the industry currently lacks a viable alternative fuel to reach this crucial target.

Liquid Wind will develop and manage facilities to produce e-methanol in large volumes, which will enable industries such as shipping, to significantly reduce their carbon emissions and improve their value proposition. As a liquid, electro-fuel or e-methanol, is easy to use, store and transport with limited modifications to existing infrastructure.

InnoEnergy, a European impact fund investing in solutions in the area of energy and cleantech will provide support and invest 1.7M euros to enable Liquid Wind to develop the world's first commercial scale e-methanol facility in Sweden.

Liquid Wind will now commence with engineering for their first e-methanol facility in Sweden, integrating proven technology from a consortium of leading experts. Six initial facilities are planned for Scandinavia, Liquid Wind will then replicate the operation internationally to meet demand and significantly reduce carbon emissions. E-methanol, from the FlagshipONE facility, will be commercially available from 2023.

New screening processes will help accelerate carbon capture research

University of Alberta researchers are helping make carbon capture more efficient, screening 120,000 carbon capturing solids in hours—instead of thousands of years.

University of Alberta researchers have developed techniques that save a significant amount of time in developing more efficient carbon capture technologies, which may help lower the costs to use the technologies and increase their adoption as a way to mitigate carbon dioxide emissions.

U of A engineering professor Arvind Rajendran and his team developed a two-step screening process that assesses carbon capture materials called zeolites in seconds rather than a day.

Zeolites work by adsorbing—basically sticking to—carbon dioxide molecules, similar to the way odours can be captured by charcoal filters in our refrigerators. In carbon capture systems, the "flue-gas" exhaust emitted from a power plant can be passed through the zeolites, trapping the CO2 before it enters the atmosphere.

Theoretically, millions of different types of materials can adsorb CO2, but to be efficient as part of an industrial process, a molecule must stick to CO2 and also release it on command when the carbon dioxide needs to be trapped or used.

However, not all zeolites are equal, Rajendran's team explains, some are much better than others at sticking to and releasing CO2.

The team, including master's graduate Vishal Subramanian Balashankar, assessed 120,000 zeolites and was able to whittle them down to only 7,000, which could then be screened down to two dozen good targets using traditional methods. One of these materials appears to be a significant improvement on the current standard material, zeolite-13x, resulting in 17 per cent more efficient power use.

The second tool—created together with U of A engineering professors Vinay Prasad and Zukui Li, and graduate students Kasturi Nagesh Pai and Gokul Subraveti—used known information about the carbon capturing molecules to predict behaviour and performance in a real-world system.

Using a machine learning algorithm eliminates the need to simulate the performance of each molecule, decreasing the computational load by a factor of 10 without losing accuracy, Rajendran noted.

Carbon capture technologies can prevent coal and natural gas power plants from emitting carbon dioxide but they currently cost so much to install and operate that power companies are hesitant to use them, he added.

"Our role is to provide these tools to help chemists find better molecules, and our expertise is designing processes that use the molecules to capture carbon," Rajendran explained.

Engineering professor Arvind Rajendran (left) in his lab with graduate students Vishal Subramanian Balashankar, Kasturi Nagesh Pai and Gokul Subraveti. The research team developed a two-step screening process to assess a potentially more efficient carbon-capturing solid in seconds, rather than the day it would take using traditional methods. (Photo: Catherine Tays)

Finding the perfect materials that fit into this goldilocks zone has always been a challenge, but the group's new machine learning tools are pointing researchers to viable new carbon capture materials, saving months lost to dead ends or work on inefficient materials. They're also helping engineers understand what carbon capture design would be most efficient.

If adsorbents are like charcoal fridge filters, machine learning is helping the researchers understand which brands are most effective at trapping odours, and how their integration in the fridge can change the effect.

The traditional process of making these decisions was slow, relying on laborious work and extensive computer simulations. Every possible molecule and every potential system design had to be individually simulated, requiring extraordinary computing power.

"The point is to quickly find molecules and systems that will reduce the cost of capturing carbon, to bring it down well below the carbon tax so it actually gets adopted," Rajendran said.

The techniques, recently published in ACS Sustainable Chemistry & Engineering and Industrial & Engineering Chemistry Research, can be adapted to speed up discoveries about other kinds of materials and processes related to climate change and industrial gas separations, including methane upgrading and oxygen purification—topics the research group is currently studying.

"We need renewable sources of energy, but we will have these hydrocarbon systems for years to come," he said. "This technology can stop emissions now, and buy us time to complete the transition."

Rajendran's work is funded by the U of A's Future Energy Systems program and Compute Canada.

More information

www.futureenergysystems.ca

www.ualberta.ca

Standardized testing eliminates amine-based CCS barriers

The International CCS Knowledge Centre is in the process of developing a skid – a portable testing apparatus, that is expected to be ready to launch in the fourth quarter of 2020.

Amine, as an essential ingredient in CCS technology in post-combustion carbon capture (PCC), has a double edge. While it allows for the most substantive cuts in CO2 emissions needed to meet climate mitigation targets, amine is also a central player in tackling a cost barrier for broad CCS deployment.

Ironically, deployment is the driving force behind the advancements in CCS technology. It is by learning that technology reduces costs, risks, and sees gains in optimization and efficiencies. Key to these gains is understanding amine behaviour, particularly its longevity in application to various sources.

Improving efficiency is a key factor in ongoing process optimization of the energy-intensive process of CCS. As such, studying the unique characteristics and behaviour of various amine solvents in combination with different flue gas streams has become a major focus of the International CCS Knowledge Centre.

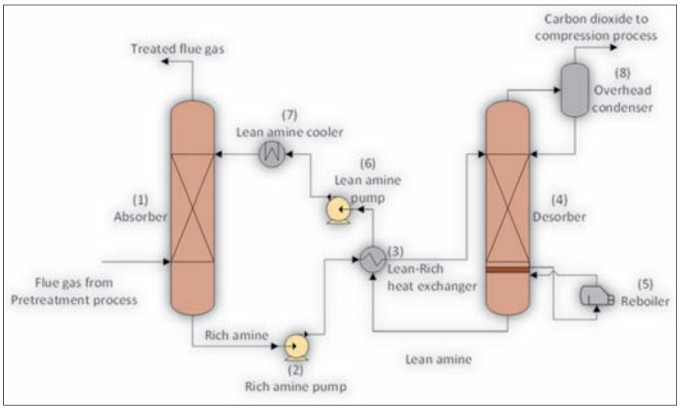
Having spearheaded the Shand CCS Feasibility Study, the Knowledge Centre notes a capture capital cost reduction of 67 per cent per tonne of CO2 for second generation CCS.

Amine solvents used in the chemical CO2 absorption process of CCS have been particularly unpredictable, and in turn, an area of concern for decision-makers contemplating a new, or looking to improve an existing, CCS project. In seeking to continue to eliminate barriers to widespread deployment of CCS and further advance this crucial technology, the Knowledge Centre established its Amine Validation Program in 2019.

Why amine post-combustion CO2 capture (PCC)?

While all methods of CCS share a particularly high capital investment and a unique set of advantages and disadvantages, Amine PCC technology allows for a very high degree of purity in the CO2 captured. The process involves using specific liquid solvents – typically amines – to separate CO2 from other components of a flue gas; capturing CO2 through a chemical reaction after a flue gas stream is generated from the fuel combustion process.

PCC is currently the most widely-employed technology used for large-scale carbon capture. PCC methodology is well-established commercially and has a distinct advantage in that it can be retrofitted to existing plants without requiring any fundamental changes.



An Amine Post Combustion Capture (PCC) system, where the amine is circulated in the system and cooled prior to being mixed with the flue gas to capture the CO2. The amine is then moved to a separate vessel where the application of heat reverses the process, releasing the pure CO2 previously captured from the amine. The amine is then cooled in order to repeat the process

Amine health and maintainability are a critical factor in the economics of operating PCC amine technology. The focus of the Amine Validation Program is to provide a platform and methodology to allow the study and comparison of the behaviour of multiple amines on a variety of different flue gas streams. Identifying key parameters is thus needed to establish common testing techniques.

Creating a standardized and practical testing approach is beneficial for amine vendors looking to create more marketable solutions as well as for project developers looking to quantify project risks. Reducing a major risk factor in the capture process then opens the door for greater deployment, which further drives down costs, as economies of scale come in to play.

How amine works

Amine PCC uses an amine-absorption process to capture and separate CO2 from a flue gas stream. Amines are derivatives of ammonia and are water-soluble organic chemicals that contain reactive nitrogen atoms and can rapidly, selectively, and reversibly react with CO2.

Amines have been used in carbon capture extensively and studied for more than 20 years. Compared to other options, the types of amines used in PCC are generally considered relatively non-volatile, inexpensive, and of moderate technical risk. They have also been utilized on a commercial scale for many years to capture CO2 from a variety of sources and for decades in other applications. Currently, amine-based CO2 capture is the most industrially-developed and widely-used method applied to the PCC method.

On post-combustion flue gas streams, the CO2 capture and separation process involves a reversible chemical reaction between the CO2 and the amine solvent (see Figure). The ability of the amine solvent to capture CO2 is key to the capture process. This ultimately yields high-purity CO2 gas that is suitable to be compressed into a supercritical state and transported by pipeline to be permanently stored or used for enhanced oil recovery (EOR).

Amine degradation

Global indications suggest that every amine solvent behaves differently from one combustion source to another due to the differences in amine chemistry, makeup of the flue gas stream, and other contaminants present in the process.

SaskPower's Boundary Dam 3 CCS Facility (BD3) – the world's first fully integrated and full-chain CCS facility on a coal-fired power plant – continues to provide valuable insight for cost-savings and operational efficiencies to achieve large-scale emission reductions. At the end of 2019, BD3 reached a major milestone in capturing, and permanently storing, three million tonnes of CO2.

According to Corwyn Bruce, VP of Technical Services at the Knowledge Centre, the research currently available on post-combustion amine-based carbon capture is insufficient for adequately understanding interactions between amines and flue gases.

"Long-term testing of amines was quite often limited in duration around the time that BD3 was built. The data we have on the behaviour of the amine used on this particular facility does not reflect the accelerated degradation that occurred closer to 3,000 or 4,000 hours of run time.

In the presence of the common components and undesirable particulates present in a flue gas stream, amines degrade and must be replaced with fresh amine solution for the capture process to continue optimally. Degradation products and operational challenges are unique to each of the different amines in combination with various flue gas streams. As such, piloting must adequately emulate the conditions of the final, full-scale process.

Skid underway

To address this research gap, the Knowledge Centre is in the process of developing a skid – a portable testing apparatus, that is expected to be ready to launch in the fourth quarter of 2020. One of the main objectives of the skid is to conduct longer-term monitoring of amine behaviour that will emulate an equivalent environment on a smaller scale. Knowledge Centre Chemist, Colin Campbell, explains how the project has a completely different focus and approach to how carbon capture systems have traditionally been studied.

"A lot of the test skids have been used for years to study the energy efficiency of a particular solvent system, but what we're interested in is how the amine reacts, how it degrades, and how it will behave, in contact with the gas stream."

Long-term testing of an amine solution for carbon capture typically occurs after the product is selected at a pilot-scale facility, which is a rather large and costly process. The ability to test multiple amines prior to selection – targeting expected amine health on specific applications and flue gas streams – is the central purpose of the Amine Validation Program.

Cross-industry application

A key design feature will allow the skid to be connected to a variety of carbon dioxide-containing gas streams beyond coal-fired plants as CCS technology is easily applicable to other heavy-emitting industries.

"If we can predict amine behaviour on a given application because of learnings from running these test skids or from building a database of contaminants vs. amine types – ultimately, that information can go into either selecting the type of amine for a particular project or the size of the amine reclamation equipment," says Campbell.

This has major implications for advancing CCS across industry sectors, allowing the same type of amine quality tests to run on flue gas streams from cement, steel, and other heavy-emitting sources that could greatly benefit from large-scale CO2 reductions.

"Cement flue gas is similar to coal-fired flue gas," says Bruce. The experience gained on the first coal systems will be instructive for achieving better outcomes sooner, in other industrial sectors."

The Knowledge Centre has already begun applying lessons learned from the BD3 CCS Facility to the Lehigh Hanson cement plant in Edmonton, Alberta in a joint CCS feasibility study that targets a 95% CO2 capture rate. The Amine Validation Program has the ability to provide further knowledge of process improvements for second-generation large-scale CCS technology in an effort to increase commerciality of this technology needed for significant emissions reductions worldwide.

Advanced real-time testing

Creating an automated system to aid in better understanding, and more closely predicting, amine behavior was also identified as a crucial feature of the program. The skid will be equipped with an instrumentation package that allows for online monitoring and analyses. The ability to remotely monitor the skid as it operates in the field will eliminate labour costs and other limitations associated with on-site monitoring. The online capabilities also allow parameters to be measured continuously in real-time versus the daily or hourly samples typically acquired and analyzed in a physical laboratory setting.

Eliminating IP barriers

Aside from ensuring the project itself is cost-effective to operate, the analytical portion of the test equipment will be designed to reduce or eliminate Intellectual Property (IP) barriers.

"Most of the information from pilot testing that's been done has not been shared because it's proprietary, which has been a real set back of long-term adoption of carbon capture. We're hoping to design the skid in an IP-neutral fashion so we don't need to know the chemical formulas of proprietary amines," says Campbell.

When proprietary amines are submitted for testing, legal ramifications and restrictions on who is permitted to conduct the laboratory tests and analyses are involved. This has caused delays and other challenges that are not conducive to accelerating deployment of CCS technology.

The skid runs will be conducted using monoethanolamine (MEA) – a benchmark amine that is the widely used in the chemical absorption process for carbon capture. Upon successful completion and operation of several skids, Campbell hopes the technology will encourage more proprietary amine vendors to take a more extensive look at the degradation behaviour of their amines.

"Surprises cost money. Hopefully we can make significant contributions to reduce capital and guarantee much-lower operating costs by selecting a different amine for an application, but there has been little study of multiple amines over a long-period. We don't know how each will behave and degrade on a similar application. These are the answers we're looking for," added Campbell.

More information

ccsknowledge.com

LAUNCH project and Biobe: moulding the future of carbon capture

LAUNCH is a three-year project funded through the ERA-NET ACT2 initiative aimed at accelerating implementation of CO2 capture across industry and enabling the development of novel solvents.

Our planet is facing an environmental crisis created by plastic overuse, yet this obscures the benefits of a versatile material, which has been used in everything from food production and medical care to electronics and construction. Now, work under way by the LAUNCH CCUS project could see plastic becoming an important ally in climate action.

One approach to capturing CO2 is to use a chemical compound known as a solvent, which is packed into the long, narrow tower of a capture plant. These solvents are recycled for re-use but a percentage is lost due to degradation, incurring a replacement cost for any capture plant operator.

The LAUNCH project is seeking ways to control this degradation and includes rigorous testing of possible countermeasures under different capture plant conditions. That's where the Norwegian company, Biobe AS, comes in.

Composite moulding at Biobe AS. Composites or GRP have much better mechanical and temperature performances than most thermoplastics and can be used in very demanding products (Image: Biobe AS)

Scientists engaged in Work Package 2 are using four test rigs to come up with strategies for controlling degradation, including the removal of products thought to cause it. Oxygen and nitrogen dioxide are two culprits. A third is iron.

Biobe is a developer and manufacturer of different products in thermoplastic and composite materials, with customers both at home and abroad. The company is known for its innovative product solutions – from simple products to larger, more complex projects – and it is well equipped to accept the challenge thrown down by the LAUNCH project.

In a bid to remove iron from the scene, Biobe is designing and building a capture demonstration plant made entirely of plastic.

Jon Hermansen, senior engineer at Biobe, explains: "Research has shown that using plastic materials in a CO2 cleaning unit will prolong the lifespan of an amino acid-based solvent. This means that the whole plant, including pipes, scrubbers, absorbers, desorbers and process equipment, such as pumps and valves, must be made in polymer materials.

"Even the heat exchangers – basically, insulators – will be formed from plastic materials. The process of making such a plant creates many challenges. So, we will be depending on the wide cooperation of research institutes and material suppliers for our work as part of the LAUNCH project."

The design of the non-metallic plant, which will be a world-first, aims to increase the efficiency of CO2 removal and reduce overall costs for large-scale facilities as well as small to medium-scale operations.

On this international project, Biobe will be working with Los Alamos National Laboratory and the University of Texas in Austin the USA, together with TNO in the Netherlands. Biobe hopes that its own long experience combined with the other partners' expertise will deliver the results the project is aiming for.

Hermansen says: "We're an experienced supplier of process cleaning applications. We've served the sulphur dioxide cleaning industry for more than 25 years and that has given us unique experience and a competitive edge. The work we undertake for LAUNCH will support climate action worldwide and will also be a valuable addition to our business portfolio."

Biobe supplies the packing used within capture plants but also provides a complete range of internal components – for absorption and various stripping operations for power plants, refineries and chemical plants – made from thermoplastics and thermoset materials to suit towers of varying designs. According to Hermansen, these products also have a high degree of corrosion resistance and that is expected to pay dividends for the LAUNCH project.

Work on the test plant's design and engineering is already under way and the first version is expected to be completed later this year.

Biobe AS is one of the most comprehensive suppliers of plastic product solutions, using multiple varieties of plastic material. Biobe is a part of the Bewi Group, which is a Norwegian owned European concern with production units and sales offices in several countries. It is located in Fredrikstad, Norway, about 100 kilometres south of Oslo, in close proximity to Sweden and the rest of Europe.

The test rigs that will be used within Work Package 2 are:

-RWE's pilot plant, Niederaussem, Germany

- AVR's waste incineration in Duiven, the Netherlands

- National Carbon Capture Center, Alabama, USA

- PACT test facility, University of Sheffield, UK

More information

launchccus.eu

www.biobe.no

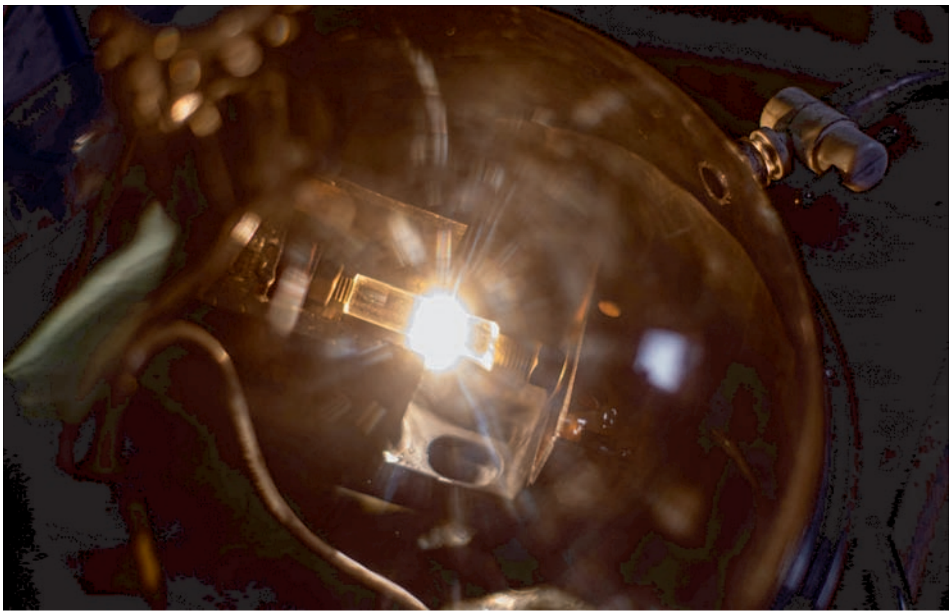
Rice lab turns carbon rich waste into valuable graphene flakes

A new process introduced by the Rice University lab of chemist James Tour can turn bulk quantities of just about any carbon source into graphene flakes at less cost than other processes.

The process is quick and cheap; Tour said the "flash graphene" technique can convert a ton of coal, waste food or plastic into graphene for a fraction of the cost used by other bulk graphene-producing methods.

"This is a big deal," Tour said. "The world throws out 30% to 40% of all food, because it goes bad, and plastic waste is of worldwide concern. We've already proven that any solid carbon-based matter, including mixed plastic waste and rubber tires, can be turned into graphene."

As reported in Nature, flash graphene is made in 10 milliseconds by heating carbon-containing materials to 3,000 Kelvin (about 5,000 degrees Fahrenheit). The source material can be nearly anything with carbon content. Waste food, plastic waste, petroleum coke, coal, wood clippings and biochar are prime candidates, Tour said. "With the present commercial price of graphene being $67,000 to $200,000 per ton, the prospects for this process look superb," he said.



Carbon black powder turns into graphene in a burst of light and heat through a technique developed at Rice University. Flash graphene turns any carbon source into the valuable 2D material in 10 milliseconds. Photo: Jeff Fitlow

Tour said a concentration of as little as 0.1% of flash graphene in the cement used to bind concrete could lessen its massive environmental impact by a third. Production of cement reportedly emits as much as 8% of human-made carbon dioxide every year.

"By strengthening concrete with graphene, we could use less concrete for building, and it would cost less to manufacture and less to transport," he said. "Essentially, we're trapping greenhouse gases like carbon dioxide and methane that waste food would have emitted in landfills. We are converting those carbons into graphene and adding that graphene to concrete, thereby lowering the amount of carbon dioxide generated in concrete manufacture. It's a win-win environmental scenario using graphene."

"Turning trash to treasure is key to the circular economy," said co-corresponding author Rouzbeh Shahsavari, an adjunct assistant professor of civil and environmental engineering and of materials science and nanoengineering at Rice and president of C-Crete Technologies. "Here, graphene acts both as a 2D template and a reinforcing agent that controls cement hydration and subsequent strength development."

In the past, Tour said, "graphene has been too expensive to use in these applications. The flash process will greatly lessen the price while it helps us better manage waste."

"With our method, that carbon becomes fixed," he said. "It will not enter the air again."

The process aligns nicely with Rice's recently announced Carbon Hub initiative to create a zero-emissions future that repurposes hydrocarbons from oil and gas to generate hydrogen gas and solid carbon with zero emission of carbon dioxide. The flash graphene process can convert that solid carbon into graphene for concrete, asphalt, buildings, cars, clothing and more, Tour said.

Flash Joule heating for bulk graphene, developed in the Tour lab by Rice graduate student and lead author Duy Luong, improves upon techniques like exfoliation from graphite and chemical vapor deposition on a metal foil that require much more effort and cost to produce just a little graphene.

Even better, the process produces "turbostratic" graphene, with misaligned layers that are easy to separate. "A-B stacked graphene from other processes, like exfoliation of graphite, is very hard to pull apart," Tour said. "The layers adhere strongly together. But turbostratic graphene is much easier to work with because the adhesion between layers is much lower. They just come apart in solution or upon blending in composites.

"That's important, because now we can get each of these single-atomic layers to interact with a host composite," he said.

The lab noted that used coffee grounds transformed into pristine single-layer sheets of graphene.

Bulk composites of graphene with plastic, metals, plywood, concrete and other building materials would be a major market for flash graphene, according to the researchers, who are already testing graphene-enhanced concrete and plastic.

The flash process happens in a custom-designed reactor that heats material quickly and emits all noncarbon elements as gas. "When

In a flash, carbon black turns into graphene through a technique developed by Rice University scientists. The scalable process promises to quickly turn carbon from any source into bulk graphene. From left: undergraduate intern Christina Crassas, chemist James Tour and graduate students Paul Advincula and Duy Luong. Photo: Jeff Fitlow

this process is industrialized, elements like oxygen and nitrogen that exit the flash reactor can all be trapped as small molecules because they have value," Tour said.

He said the flash process produces very little excess heat, channeling almost all of its energy into the target. "You can put your finger right on the container a few seconds afterwards," Tour said. "And keep in mind this is almost three times hotter than the chemical vapor deposition furnaces we formerly used to make graphene, but in the flash process the heat is concentrated in the carbon material and none in a surrounding reactor.

"All the excess energy comes out as light, in a very bright flash, and because there aren't any solvents, it's a super clean process," he said.

Luong did not expect to find graphene when he fired up the first small-scale device to find new phases of material, beginning with a sample of carbon black. "This started when I took a look at a Science paper talking about flash Joule heating to make phase-changing nanoparticles of metals," he said. But Luong quickly realized the process produced nothing but high-quality graphene.

Atom-level simulations by Rice researcher and co-author Ksenia Bets confirmed that temperature is key to the material's rapid formation. "We essentially speed up the slow geological process by which carbon evolves into its ground state, graphite," she said. "Greatly accelerated by a heat spike, it is also stopped at the right instant, at the graphene stage.

"It is amazing how state-of-the-art computer simulations, notoriously slow for observing such kinetics, reveal the details of high temperature-modulated atomic movements and transformation," Bets said.

Tour hopes to produce a kilogram (2.2 pounds) a day of flash graphene within two years, starting with a project recently funded by the Department of Energy to convert U.S.-sourced coal. "This could provide an outlet for coal in large scale by converting it inexpensively into a much-higher-value building material," he said.

Tour has a grant from the Department of Energy to scale up the flash graphene process, which will be co-funded by the start-up company, Universal Matter Ltd.

The Air Force Office of Scientific Research and the National Science Foundation supported the research.

More information

www.rice.edu

Carbon dioxide as a raw material for the chemical industry

VTT and its business partners have launched a two-year project to develop a concept for a process to capture and use carbon dioxide. www.beccu.fi

The aim is to use the carbon dioxide produced during bioenergy production as a raw material for speciality chemicals. As certain end products have a long lifecycle, the concept may even lead to negative emissions, that is, products that act as carbon sinks.

CO2 can be captured both from the air and from processes at power plants and production facilities. It can be used to replace fossil fuels as a raw material in manufacturing numerous chemical products. VTT has previously evaluated that facilities that utilise and process biomass could be suitable pioneers for viable carbon dioxide capture.

Although captured carbon dioxide has been studied often as a raw material for transport fuels, extremely affordable electrical energy would usually be required to make these synthetic fuels viable. For the BECCU project, VTT and its business partners have selected chemicals, and in particular polyols, as the primary end products. Polyols are in turn the raw materials for polyurethane products, such as insulation materials and foam adhesives.

The goal is to determine whether polyols can be profitably manufactured from bio-based carbon dioxide and hydrogen in the current market situation. The project is developing a concept for the entire processing chain, from the use of biomass in energy production all the way to the capturing of carbon dioxide and chemical manufacture. The aim is to prepare this concept to the next point where industrial-scale investments can be targeted.

- Polyurethane products are increasingly being used in construction industry insulation in the global markets, so it's important that the fossil raw materials used in these products are replaced by bio-based and recycled materials, both as part of the Finnish chemical industry's sustainability targets and to strengthen its market position, says Henri Nieminen from Finnfoam.

- Neste are seeking solutions to reduce CO2 emissions by 20 million tons per year by 2030. The company is involved in BECCU because the project seeks possibilities for turning carbon dioxide from a problem into an opportunity, says Neste's Lars Peter Lindfors, Senior Vice President, Innovation.

- Valmet's mission is to convert renewable resources into sustainable results. The concept of capturing biomass-based carbon dioxide for the production of new end products is a good fit with our mission. Achieving climate targets calls for new solutions and verifying them with the whole value chain – and BECCU project is ideally suited for this, says Ari Kokko, Director, Technology and R&D, Energy Business Unit, Valmet.

VTT's mobile synthesis unit MOBSU for bench-scale process development. (Photo by COMSYN-project)

Power-to-X processes to be piloted

The BECCU project will compare a variety of processes to capture carbon dioxide from biomass use in energy production. The second main raw material of polyols – hydrogen – will be produced using renewable electricity or supplied from industrial by-product sources. The team will test each stage of the process using VTT's pilot and laboratory test equipment and assess the techno-economic requirements for their entire lifecycle.

The concept will also be compared to other Power-to-X concepts, that is, processes in which transport fuels and other chemicals, such as methanol and methane, can be produced from carbon dioxide and hydrogen.

The BECCU project's total budget is approximately EUR 2 million, and its main sponsor is Business Finland. It is part of Business Finland's Green Electrification ecosystem, which was launched at the beginning of 2020 and seeks to develop Power-to-X processes.

- BECCU is one of the first co-innovation packages to be launched within the ecosystem, that is, in which research institutes and companies work together to develop new technologies and services. In addition to major driver companies, a significant number of SMEs are joining the project and getting involved in an extensive research programme. The project will play a major role in developing Power-to-X technologies and identifying new applications, says Pia Salokoski, a leading financing expert at Business Finland.

In addition to VTT and Business Finland, the following stakeholders are also participating in the project: Valmet, Top Analytica, Metener, Finnfoam, Kiilto, Mirka, Pirkanmaan Jätehuolto, CarbonReUse, Neste, Helen, the Chemical Industry Federation of Finland along with number of international research partners. Alongside the public project, the partners will also be launching their own development projects, which will both utilise the project's results and bring market perspectives to public research.

CO2 DataShare launches open, digital data sharing portal

CO2 DataShare has launched a web-based digital portal for sharing reference datasets from pioneering CO2 storage projects. **co2datashare.org**

The new portal will enable researchers and engineers to improve their understanding, reduce costs and minimize uncertainties associated with CO2 storage.

"We hope that many data-owners within the CCS community will share their data on this new portal. Sharing of reference datasets from pioneering CO2 storage projects is essential to accelerate improved understanding, build capacity, reduce costs and minimize uncertainties associated with CO2 storage in deep geological formations", says Grethe Tangen, Project Manager CO2 DataShare.

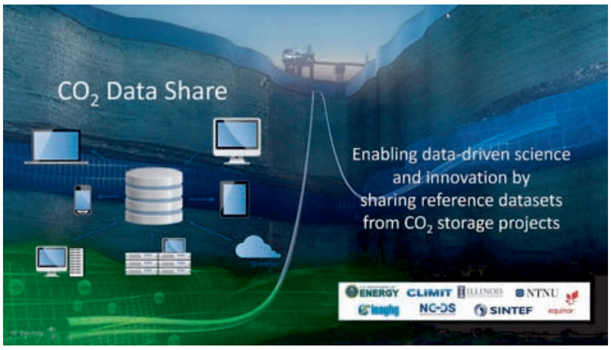
Lack of relevant data has been a barrier for CCS research and deployment, a barrier that can be overcome by access to open data. The CO2 DataShare project was established in 2018 to accelerate the deployment of CCS by providing open access to CO2 storage data.

“We are very excited to see the CO2 DataShare Portal launch", says Sallie Greenberg, Associate Director – Energy & Minerals at Illinois State Geological Survey. "This international collaborative effort has been several years in the making. Availability of data will allow for refinement of models, development of new methods for plume detection, and potentially help drive commercialization of this important technology.”

Building confidence in CO2 storage

CO2 DataShare aims to share curated datasets from pilot and industry-scale projects to drive research and development. This is essential for building confidence in CO2 storage as a greenhouse gas control strategy. The portal offers a simple, standard, and low-cost solution for making high-quality data available to the CCS community worldwide.

“Interchange of data from established CO2 storage sites will help in regions of the world where CCS is less well developed, especially for stakeholders including investors and operators who have limited experience in CCS. As data acquisition grows there is the positive prospect of greater international comparison, collaboration and enhanced experience,” says James Craig, Technical Programme Manager, IEAGHG.



The platform's two first data sets are available for use

The two first datasets to be shared are provided by the Sleipner Group consisting of Equinor Energy AS (operator), ExxonMobil Exploration and Production Norway AS, LOTOS Exploration and Production Norge AS and KUFPEC Norway AS. They include:

- The Sleipner 2019 Benchmark model, containing a simulation grid with associated data, suited to advance modelling tools and the understanding of CO2 flow dynamics.

- The Sleipner 4D seismic data entailing 14 years of injection and a total of 6 repeated seismic sets gathered. The base line data gathered before the CO2 injection started will also be released.

"Sleipner is perhaps the best know CCS project in the world – but there is still much to be learned from it. I hope this new release of seismic and reservoir data will allow new insights to be gained on this long-running CO2 injection project. Especially, we hope to calibrate the next generation of dynamic flow models against this reference case" says Philip Ringrose, Geoscience Specialist, Equinor.

The CO2 DataShare platform is open to all data owners

By providing simple measures for preparing and sharing CO2 storage datasets from industry projects, demonstration projects and field tests, CO2 DataShare can lower the threshold for data owners to share with the CCS community within agreed terms of use.

"Our hope is that other data owners will follow Equinor and collaborate with the project to share their data through the portal. Data documentation, definition of metadata and clarification of access rights and licensing terms are tasks done by the data provider in collaboration with CO2 DataShare", says Grethe Tangen, Project Manager CO2 DataShare.

CO2 DataShare is a project established in 2018 by the CO2 Storage Data Consortium, an open international network for data and knowledge exchange, initiated by Equinor, SINTEF, University of Illinois and IEAGHG in 2016. CO2 DataShare has received financial support from Gassnova and US Department of Energy. The project is coordinated with the Norwegian CCS Research Centre, NCCS.

The portal builds on UNINETT Sigma2's solution for data storage combined with a tailored frontend developed using the open source software CKAN. UNINETT Sigma2 is a non-profit company that manages the national infrastructure for computational science in Norway (**www.sigma2.no**).

The default and preferred model is for the datasets to be freely downloadable under an open license. All documentation of the data and the metadata is openly accessible.

CO2CRC Otway Stage 2C project delivers first results

The project has provided important findings into migration and monitoring of carbon dioxide injected underground.

CO2CRC injected 15,000 tonnes of CO2 approximately 1,500 meters underground at its Otway National Research Facility located in Nirranda South, Victoria. The CO2 was injected into a saline aquifer between December 2015 and April 2016. The CO2 plume was then detected and tracked during the injection and in the years after.

The monitoring was done primarily using an array of geophone receivers buried just under the surface to detect the seismic signal paired with conventional vibroseis where a seismic signal is produced by a truck-mounted seismic vibrator. Surface orbital vibrators were also successfully trialled as a seismic signal source enabling monitoring data to be acquired continuously.

The research, led by Curtin University and supported by CSIRO and Lawrence Berkley National Laboratory, USA, demonstrated that a small amount of CO2 (as little as 5,000 tonnes), can be detected using seismic monitoring tools and its movement underground successfully mapped.

The demonstration provides CCS stakeholders with confidence that any movement of the injected CO2 outside of the storage complex can be quickly detected. The project also trialled a variety of new seismic monitoring techniques.

"The ability to reliably predict the movement of CO2 and optimise the use of seismic monitoring to validate the plume migration path will be invaluable to CCS project operators and regulators around the world," said David Byers, CEO of CO2CRC.

"Our success with the Stage 2C project in observing the behaviour of a small CO2 plume and understanding the resolution and sensitivity of seismic monitoring has paved the way for CO2CRC's biggest project to date: Otway Stage 3," he said.

A CO2 plume was observed migrating through the subsurface at CO2CRC's Otway National Research Facility primarily using an array of geophone receivers buried just under the surface to detect the seismic signal

In 2019, work on Otway Stage 3 began with the expansion of infrastructure at the Otway National Research Facility through the drilling of four new 1600-metre-deep monitoring equipped with the latest technologies in fibre optics sensing and subsurface gauges.

Otway Stage 3 will demonstrate the next generation of sub-surface monitoring technologies and improve the efficiency of storage monitoring.

These new technologies provide data quicker and cost significantly less than the seismic surveys currently used with initial estimates showing cost savings of up to 75 percent," Mr Byers said.

A workflow for verifying the stabilisation of the CO2 plume using seismic data and dynamic modelling has been developed under Stage 2C and will be tested in the next phase of the project, expected to be completed by June 2020.

"Our hope is that the applied scientific and technological research conducted at CO2CRC's Otway National Research Facility will lead to more CCS projects around the world, allowing CCS to play a vital role in meeting the dual challenge of reducing emissions across all major industry sectors while meeting the growing global demand for affordable and reliable energy," Mr Byers said.

The CO2CRC Otway Stage 2C project is jointly funded through its industry members and research partners, the Australian Government, the Victorian State Government and COAL21 through ANLEC R&D.

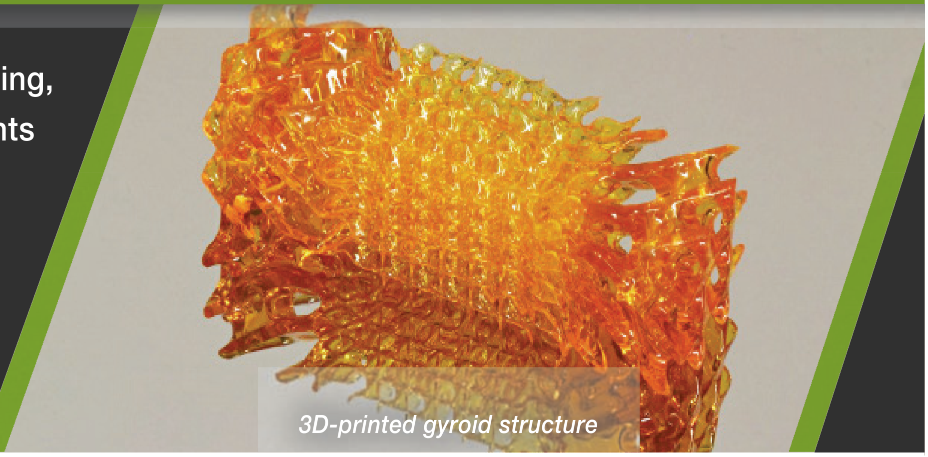
More information

www.co2crc.com.au

Advanced Manufacturing to Drive Down Capture Costs

Improving Performance Through Additive Manufacturing

Additive manufacturing, using 3D printing, enables the development of components for carbon capture equipment that intensify heat and mass transfer, improve process performance, and reduce overall equipment size, lowering capital and operating costs.

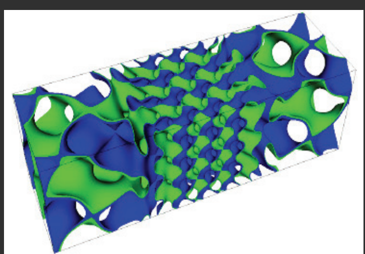


3D-printed gyroid structure

DOE/FE/NETL is currently supporting three projects that are using 3D printing to produce rapid prototypes with the potential to capture CO_2 more efficiently and economically.

Lawrence Livermore National Laboratory

Designing and fabricating high-efficiency reactors using novel geometries that support transformational solvent-based capture technologies.

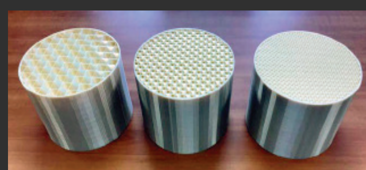


ION ENGINEERING

Developing a 3D-printed absorber with integrated packing and internal cooling capabilities to help optimize solvent-based capture.

OAK RIDGE National Laboratory

Producing intensified devices that combine heat and mass transfer operations to drive down costs of solvent-based capture processes.



Progress to Date

Lawrence Livermore National Laboratory: Silicon-based gyroid structures have been created with one micron resolution using stereo-lithography.

ION Engineering: Both plastic and metal absorbers have been 3D-printed for testing and analysis.

Oak Ridge National Laboratory: An aluminum version of a column packing structure with built-in heat exchange has been successfully 3D-printed.

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