Carbon Capture Journal

CCS in the U.S.

Exceeding expectations - recent developments in U.S. CCS policy

12,893,780 metric tonnes of CO2 injected as of July 19, 2016

Global Thermostat's low cost CO2 removal tech

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12,893,780 metric tonnes of CO2 injected as of July 19, 2016

The CO2 has been injected in the United States as part of DOE's Clean Coal Research, Development, and Demonstration Programs.

Regional Partnerships

The projects currently injecting CO2 within DOE's Regional Carbon Sequestration Partnership Program and the Major Demonstration Program are detailed below.

DOE's Regional Carbon Sequestration Partnerships (RCSPs) were established in 2003 to develop the technology, infrastructure, and regulations needed to implement large-scale CO2 storage in different regions and geologic formations. The network of seven RCSPs are currently conducting field tests which involve integrated system testing and validation of geologic storage, simulation and risk assessment, and monitoring, verification, and accounting (MVA) technologies in different depositional environments.

In addition, the RCSPs are studying possible regulatory and infrastructure requirements that would be needed should carbon capture and storage be deployed on a commercial basis.

The seven RCSPs are comprised of more than 400 diverse organizations covering 43 states and four Canadian provinces. The following Regional Carbon Sequestration Partnerships are currently conducting large-scale CO2 injection field tests:

Plains CO2 Reduction Partnership (PCOR): For the Bell Creek large-scale project, the PCOR Partnership is working with Denbury Onshore LLC to develop robust, practical, and targeted support programs to study incidental CO2 storage associated with a commercial-scale enhanced oil recovery operation.

Midwest Geological Sequestration Consortium (MGSC): MGSC has partnered with the Archer Daniels Midland (ADM) Company and Schlumberger Carbon Services to conduct a large-volume, saline reservoir storage field project at ADM's agricultural products processing complex in Decatur, Illinois. The project is injecting 1 million metric tons of CO2 over three years into a deep saline formation in the Illinois Basin.

Air Products' Port Arthur hydrogen production facility in Texas

Midwest Regional Carbon Sequestration Partnership (MRCSP): MRCSP's large-volume CO2 injection and storage test is focused on the Niagaran Reef Complex located in Ostego County in northern Michigan. The site is managed by MRCSP's partner, Core Energy, and is in the vicinity of natural gas processing plants that provide CO2 for the enhanced oil recovery operations.

Southeast Regional Carbon Sequestration Partnership (SECARB): SECARB is conducting two large-volume injection field projects - one in the lower Tuscaloosa Formation (Cranfield site) and one in the Paluxy Formation (Citronelle site). These formations are key components of a larger, regional group of similar formations, called the Gulf Coast Wedge.

Southwest Regional Partnership (SWP): SWP is characterizing, modeling, monitoring, and tracking at least 1 million metric tons of CO2 at an ongoing oil recovery operation in Ochiltree County, northern Texas. The primary target reservoir is the Pennsylvanian-age Morrow Sandstone Formation within the Farnsworth Unit of the Anadarko Basin.

Major demonstrations

Air Products and Chemicals, Inc., is demonstrating a state-of-the-art system to concentrate CO2 from two world-class scale steam methane reformer (SMR) hydrogen production plants located in Port Arthur, Texas.

Air Products has successfully retrofitted its two Port Arthur SMRs with a vacuum swing adsorption system to separate the CO2 from the process gas stream, followed by compression and drying processes. The compressed CO2 is then delivered to a Denbury pipeline for transport to Texas enhanced oil recovery projects in the West Hastings Field, where a monitoring, verification, and accounting program ensures the injected CO2 remains in the geologic formation.

The project is currently in operation. The MVA program to monitor the injected CO2 was designed and the implementation started once CO2 capture began. The project successfully captured and sent for sequestration the one millionth metric ton of CO2 in April 2014.

More information

www.fossil.energy.gov

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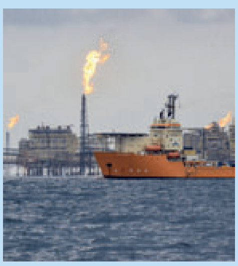
Front cover:

Gas flaring is still common in the oil and gas industry – Fluenta shows how business can derive new revenue streams through the transition from waste to capture of CO2 (Image ©Fluenta)



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Leaders - CCS in the United States

Projects and policy

CO2 utilisation conference report

Capture and utilisation

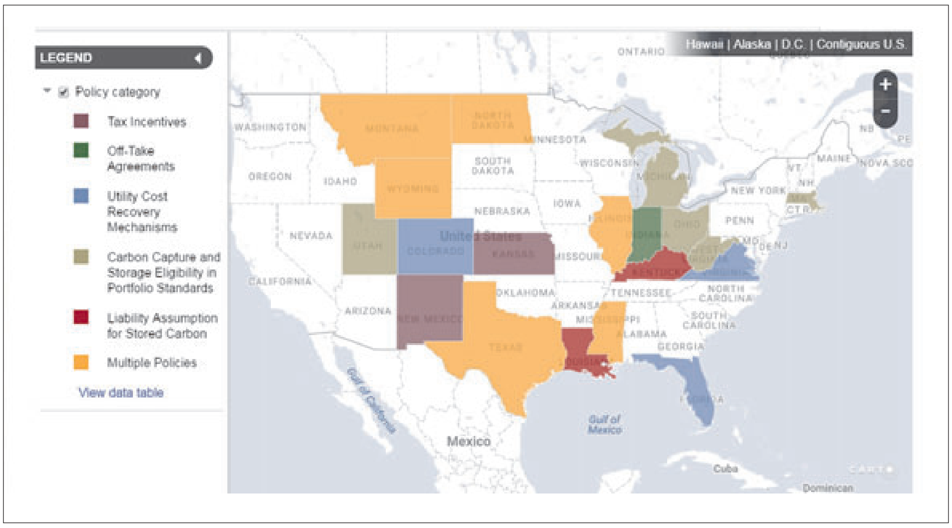
Transport and storage

Exceeding expectations: recent developments in U.S. CCS policy

A raft of bipartisan proposals and state initiatives show that even in an election year, there are areas of energy policy where leaders of both parties and stakeholders from diverse sectors of the economy can find common ground.
By Fatima Ahmad, Solutions Fellow, C2ES

Encouraged by the landmark Paris Agreement in December 2015 and motivated by the need to avoid stranded assets and preserve jobs in the power sector, policymakers took seriously the challenge of accelerating deployment of carbon capture, use and storage (CCUS or carbon capture).

Midway through the year, the International Energy Agency issued a report concluding that financial and policy support for carbon capture is not at a sufficient level to ensure an adequate pipeline of carbon capture projects that will enable the world to stay on track to meet mid-century goals of keeping global warming within 2 degrees Celsius of pre-industrial levels.[1] Bipartisan proposals that are before Congress this year would encourage CCUS technology. State political leaders also supported carbon capture in notable ways this year.



Financial incentives for CCS in the United States by state (Source: C2ES)

H.R. 4622, the Carbon Capture Act

On Feb. 25, 2016, Rep. Mike Conaway (D-Texas) introduced H.R. 4622, the Carbon Capture Act, a bill to extend and expand Section 45Q, which is the primary tax credit for the use of carbon dioxide in enhanced oil recovery (CO2-EOR), a form of tertiary production.[2]

In the United States, carbon dioxide has been safely used in commercial enhanced oil recovery for more than 40 years. The United States produces about 4 percent of its oil through CO2-EOR. However, most of the carbon dioxide used is from naturally occurring underground reservoirs instead of from man-made sources. In addition to the climate benefits of reducing the amount of carbon dioxide vented into the atmosphere, CO2-EOR maximizes production from existing oil fields and may displace more carbon-intensive imported crude oil.

Rep. Conaway's bill has 39 co-sponsors: 26 Republicans and 13 Democrats. These co-sponsors hail from 24 states and all regions of the country. This broad support challenges the notion that energy policy debates must be polarized and partisan.

H.R. 4622 provides four changes to 45Q. First, it would remove the existing cumulative cap of 75 million tons of CO2 and make the tax credit permanent. With less than half of the credits left for new projects to use, there is too much uncertainty for carbon capture project developers to secure financing.[3] By making the tax credit permanent, the bill aims to establish certainty that would enable carbon capture project financing.

Second, the bill would increase the value of the credit per ton of CO2. Under current law, there is a credit of $10 per ton of CO2 for EOR and $20 per ton of CO2 for saline storage. Rep. Conaway's bill would increase these values to $30 for both EOR and saline storage. These increases would ramp up over time reaching their full value in 2025.

Third, the bill would lower the threshold for qualifying facilities to 150,000 tons of CO2 for both power plants and industrial facilities. Industrial facilities that emit CO2 include ethanol plants; natural gas processing facilities; steel, cement, fertilizer and chemical plants; hydrogen production plants, and refineries.[4] Capture of industrial CO2 emissions is critical because the sector accounts for almost 25 percent of global greenhouse gas emissions.[5]

For these industrial sources, the cost to cap-

1. International Energy Agency, Tracking Clean Energy Progress 2016 11, 30-31, available at https://www.iea.org/etp/tracking2016/
2. See H.R. 4622, 114th Cong. (2016) available at https://www.congress.gov/bill/114th-congress/house-bill/4622
3. The IRS announced that almost half of the credits available under the cumulative cap have been claimed. U.S. Internal Revenue Service, Notice 2015-44, Credit for Carbon Dioxide Sequestration: 2015 Section 45Q Inflation Adjustment Factor (2015), available at https://www.irs.gov/pub/irs-drop/n-15-44.pdf
4. In the U.S., there are states and regions that will have candidates for carbon capture at lower-cost industrial facilities before they do in the power sector.

ture CO_2 is often lower than for power plants. Technology to separate the CO_2 stream has been used in natural gas processing for decades. The by-product CO_2 stream is often of higher purity, i.e. less mixed with other gases, than power plant emissions. Importantly, there is no alternative to CCUS to achieve deep decarbonization in the industrial sector because production of CO_2 is often an inherent part of the chemical or industrial process. By lowering the threshold for industrial sources of CO_2, the bill aims to incentivize investment in industrial carbon capture projects.

Finally, the bill would allow transferability of the credit within the chain of CO_2 custody. This change would allow entities with little or no tax liability to benefit from the incentive by transferring it to entities with the ability to use the credit.

In the Senate, companion legislation was offered on April 12, 2016, by Sens. Heidi Heitkamp (D-ND) and Shelly Moore Capito (R-WV) in the form of an amendment to the Federal Aviation Administration (FAA) reauthorization bill.[6] The amendment had bipartisan support from two Democrats and five Republicans.[7] While the amendment was voted into the tax title of the FAA bill, the tax title was ultimately dropped for other reasons.[8]

S. 2012, Energy Policy Modernization Act

On Apr. 20, 2016, the Senate passed a broad energy bill authored by Senate Energy Committee Chairwoman Lisa Murkowski (R-Alaska) and Ranking Member Maria Cantwell (D-WA).[9] The bill was approved 85-12, demonstrating bipartisan support. Section 3403 of the bill authorizes a new research, development and demonstration program at the U.S. Department of Energy (DOE) on CCUS technology.[10]

Section 3404, added by Sens. Heitkamp and Capito and co-sponsored by six Democrats and four Republicans,[11] directs the DOE to report on long-term contracts to provide price stabilization support for carbon capture projects, a mechanism that is often referred to as a Contract for Differences (CfD).[12] The DOE report would identify the costs and benefits of entering into CfDs and would outline options for how such CfDs could be structured and describe regulations that would be necessary to implement such a program.[13]

North American Climate, Clean Energy, and Environment Partnership

On Jun. 29, 2016, President Barack Obama, Canadian Prime Minister Justin Trudeau, and Mexican President Enrique Peña Nieto announced the North American Climate, Energy, and Environment Partnership.[14] The three nations aim to achieve 50 percent clean power generation by 2025, including through CCUS technology.

One of the goals identified in the White House Action Plan is leveraging participation in Mission Innovation[15] by identifying joint R&D initiatives to advance CCUS technology. By highlighting the role of CCUS in achieving deep decarbonization in North America, there is a renewed opportunity to focus on how the three nations can work together.

S. 3179, the Carbon Capture Utilization and Storage Act

On July 13, 2016, Sens. Heitkamp and Sheldon Whitehouse (D-RI) introduced S. 3179, the Carbon, Capture, Use and Storage Act, along with co-sponsoring Sens. Jon Tester (D-MT), Brian Schatz (D-Hawaii), Cory Booker (D-NJ), Tim Kaine (D-VA), and Bob Casey (D-PA).[16] Republican co-sponsors include Sens. Capito and Blunt and Senate Majority Leader Mitch McConnell, putting the Kentucky Republican and some of the Senate's leading advocates for climate action on the same side.

The Senate bill allows forms of CO_2 utilization beyond EOR to be eligible for the tax credit. Under the bill, utilization is expanded to include the fixation of CO_2 "through photosynthesis or chemosynthesis, such as through the growing of algae or bacteria," chemical conversion of CO_2 to a material or chemical compound in which CO_2 is securely stored, or the use of CO_2 for "any other purpose for which a commercial market exists."[17] A leading example of carbon dioxide use beyond EOR is algae biofuels.

The Senate bill would extend the tax credit for seven years and would allow the credit to

5. Global CCS Institute, Global Status of CCS: Special Report – Introduction to Industrial Carbon Capture and Storage 4 (2016), available at https://www.globalccsinstitute.com/publications/industrial-ccs
6. H.R. 636, 114th Cong. (2016), available at https://www.congress.gov/amendment/114th-congress/senate-amendment/3645
7. Senators Joe Donnelly (D-IN), Jon Tester (D-MT), Roy Blunt (R-MO), John Barrasso (R-WY), Dan Coats (R-IN), Steve Daines (R-MT), and Mike Enzi (R-WY).
8. Geof Koss, Blame Game Follows Collapse of Senate Tax Talks (E&E News PM, Apr. 12, 2016).
9. S. 2012, 114th Cong. (2016), available at https://www.congress.gov/bill/114th-congress/senate-bill/2012
10. Section 3403 establishes a new coal technology program, which includes programs for research and development, large-scale pilot projects, demonstration projects, and co-fired biomass-coal projects. Id. The section authorizes $632 million annually from 2017 – 2020, and $582 million in 2021. DOE continues to do substantial work and focus domestic and international policy efforts on CCUS. An important domestic DOE initiative is the creation of seven Regional Carbon Sequestration Partnerships to help develop infrastructure and regulations for CCUS technology and sequestration. An important international DOE initiative is the Carbon Sequestration Leadership Forum, a ministerial-level panel that meets to advance CCUS RD&D worldwide.
11. Senators Joe Manchin (D-WV), Cory Booker (D-NJ), Sheldon Whitehouse (D-RI), Jon Tester (D-MT), Roy Blunt (R-MO), Al Franken (D-MN), Joe Donnelly (D-IN), John Barrasso (R-WY), Dan Coats (R-IN), and Mike Enzi (R-WY).
12. S. 2012, 114th Cong. (2016), available at https://www.congress.gov/114/bills/s2012/BILLS-114s2012es.pdf
13. As context, carbon capture projects often face steep financing challenges. This is because one of the main uses of CO_2 that is in commercial operation today is CO_2-EOR and the revenue from the sale of CO_2 for EOR is dependent on volatile oil prices. The futures market for oil prices does not enable the type of commercial hedge that is needed to finance these projects. A CfD would address that market weakness by providing a reference oil price that would remain the same over the duration of the contract. When oil prices are above the reference oil price, the developer would pay the U.S. Treasury. When oil prices fall below the reference oil price, the Treasury would pay the developer. By providing certainty, a Federal CfD would make it easier for carbon capture projects to reach financial close.
14. The White House, North American Climate, Clean Energy, and Environment Partnership Action Plan (Jun. 29, 2016), available at https://www.whitehouse.gov/the-press-office/2016/06/29/north-american-climate-clean-energy-and-environment-partnership-action
15. Mission Innovation is an initiative that was launched in Paris in November 2015. Through this initiative, 20 nations have committed to doubling their clean energy R&D investments over five years. The Breakthrough Energy Coalition is an independent initiative spearheaded by Bill Gates that launched simultaneously with Mission Innovation. Through the Breakthrough Energy Coalition, a global group of private investors have committed to commercializing the research that is funded by Mission Innovation.
16. S. 3179, 114th Cong. (2016), available at https://www.congress.gov/bill/114th-congress/senate-bill/3179
17. S. 3179, 114th Cong. § 2 (2016), providing a new Section 45Q(e)(7)(A).

be claimed for 12 years.[18] For new facilities, the Senate bill increases the value per ton of CO2 of the tax credit to $35 for EOR and $50 for geologic storage.[19] The bill lowers the threshold for qualifying facilities to 100,000 tons for industrial facilities.[20] Finally, the Heitkamp-Whitehouse bill provides the tax credit to the owner of the carbon capture equipment.[21]

Other Federal Efforts

H.R. 2883, the Master Limited Partnerships Parity Act and S. 2305, the Carbon Capture Improvement Act.

Developments this year build on previous efforts to promote carbon capture. On June 24, 2015, Rep. Ted Poe (R-Texas) and Rep. Mike Thompson (D-CA) re-introduced H.R. 2883, the Master Limited Partnerships Parity Act, which would extend the publicly traded partnership ownership structure available for certain oil and gas activities to renewable energy development.[22] The bill would also extend the tax treatment to carbon capture for EOR or other secure geologic storage. The bill was co-sponsored by six Democrats and six Republicans.[23]

Additionally, on Nov. 19, 2015, Sens. Michael Bennet (D-CO) and Rob Portman (R-OH) introduced S. 2305, the Carbon Capture Improvement Act, which would allow the use of tax-exempt private activity bonds (PABs) issued by state or local governments to finance carbon capture projects.[24]

From the perspective of project developers, the extension and expansion of Section 45Q will do the most to accelerate the deployment of CCUS technology, although the MLP and PAB efforts will play a critical role.[25] Like with other low- and zero-carbon energy technologies such as wind and solar, multiple and complementary incentive policies are often more effective in enabling investment to drive deployment than any single incentive policy.

State Policy

A number of states have demonstrated leadership on carbon capture policy in 2016 by voicing growing support for federal incentives. In February, the National Association of Regulatory Utility Commissioners (NARUC) adopted a resolution urging Congress and the Obama Administration to support state efforts on CCUS including CO2-EOR.[26]

In June, the Western Governors' Association followed up on a June 2015 resolution supporting CO2-EOR[27] with a letter of support for federal incentives for this technology.[28] In July, Montana Governor Steve Bullock released Montana's Energy Future Blueprint, which highlights the need for federal and state support of accelerated commercial deployment of CCUS technology.[29]

Last fall, the Southern States Energy Board also issued a resolution supporting federal incentives for CO2-EOR.[30]

Conclusion

Despite encouraging progress at the federal and state levels, formidable challenges lie ahead. Developers of carbon capture projects face serious obstacles in obtaining financing. Deployment of carbon capture technology is not on track to meet our climate goals. Fewer than half of the Intergovernmental Panel on Climate Change models were able to stay within a 2-degree scenario without CCUS.[31] Without carbon capture, the costs of climate change mitigation increase by 138 percent.[32] Carbon capture projects are capital-intensive and require long lead times to reach commissioning. In this context, the need for action is urgent.

What we have seen this year is that U.S. political leaders are able find common ground on energy policy where the goals of emissions reduction, energy security, and economic development converge. Looking forward, there is reason to hope that through working together on carbon capture policy this year, elected officials on both sides of the aisle have developed working relationships and built bridges that will enable continued action on climate in the next administration.

More information

www.c2es.org

18. S. 3179, 114th Cong. § 2 (2016), providing a new Section 45Q(a)(3) and 45Q(d)(1)(A). The determination of eligibility is based on the date that a project commences construction. This provides greater certainty for investors than the existing cumulative cap of 75 million tons of CO2 but not as much certainty as a permanent tax credit.
19. S. 3179, 114th Cong. § 2 (2016), providing a new Section 45Q(b)(1). The value of the credit ramps up over time. The Senate bill does not increase the value of the credit for existing facilities. S. 3179, 114th Cong. § 2 (2016), providing a new Section 45Q(a)(1)-(2).
20. S. 3179, 114th Cong. § 2 (2016), providing a new Section 45Q(d)(1)(B). For power plants, the threshold for power plants remains at 500,000 tons. This would exclude some smaller demonstration carbon capture projects at power plants. The threshold is 25,000 for projects that utilize CO2.
21. S. 3179, 114th Cong. § 2 (2016), providing a new Section 45Q(e)(5). Like H.R. 4622, this would enable rural electric cooperatives without tax liability to benefit from the incentive because the incentive could be claimed by a third-party that puts up the investment funds in the equipment. This would reduce the cost of capital for these projects.
22. H.R. 2883, 114th Cong. (2016), available at https://www.congress.gov/bill/114th-congress/house-bill/2883
23. Representatives Mark Amodei (R-NV-2), Peter Welch (D-VT-At Large), Paul Gosar (R-AZ-4), Earl Blumenauer (D-OR-3), Mike Coffman (R-CO-6), Jerry McNerney (D-CA-9), Mia Love (R-UT-4), Tammy Duckworth (D-IL-8), Carlos Curbelo (R-FL-26), John Delaney (D-MD-6), Chris Gibson (R-NY-19), and Scott Peters (D-CA-52).
24. Access to tax-exempt private activity bonds will provide project developers an important tool in a broader toolkit of measures needed to help attract private investment and finance carbon capture projects. The benefits to consumers and businesses of PABs include their tax-exempt status and the fact that they can be paid back over a longer period of time. S. 2305, 114th Cong. (2016), available at https://www.congress.gov/bill/114th-congress/senate-bill/2305
25. MLPs and PABs will be especially helpful for electric power generation and some industrial sectors where the costs of carbon capture remain high.
26. National Association of Regulatory Utility Commissioners, ERE-1: Resolution on Carbon Capture and Enhanced Oil Recovery (Feb. 17, 2016), available at http://pubs.naruc.org/pub/66436AF7-DFB2-C21E-43B2-1AE83A02D8F5
27. Western Governors' Association, Policy Resolution 2015-06 (Jun. 25, 2015), available at http://westgov.org/images/images/RESO_EOR_15_06.pdf
28. Letter from Matthew Mead, Governor, State of Wyoming, and Steve Bullock, Governor, State of Montana to Rep. Mike Conaway (R-TX-11) and Sens. Heidi Heitkamp (D-ND) and Shelley Moore Capito (R-WV) (Jun. 3, 2016), available at http://westgov.org/letters-testimony/343-energy/1195-letter-governors-support-enhanced-oil-recovery-technology
29. State of Montana, Montana's Energy Future (Jun. 21, 2016), available at https://governor.mt.gov/Newsroom/ArtMID/28487/ArticleID/4325
30. Southern States Energy Board, Resolution Supporting Carbon Capture and Storage and Enhanced Oil Recovery (Sep. 28, 2015), available at http://www.sseb.org/wp-content/uploads/2015/09/6.2015.pdf
31. Intergovernmental Panel on Climate Change, Working Group III Contribution to the Fifth Assessment Report (2014), available at https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_full.pdf
32. Ibid.

Global Thermostat's low cost carbon removal technology

What if we could place more than a century of climate change into reverse? Global Thermostat is a new company founded in 2010 that takes CO2 out of the air thereby removing greenhouse gases that cause climate change.

By Graciela Chichilnisky and Peter Eisenberger

Here's an example of how it works: If GT technology is attached to a renewable or carbon-emitting power plant, it removes more carbon from the air than the plant emits. About 3 times as much for renewable power plants using it's Direct Air Capture Technology (DAC). It makes the combined facilities "carbon negative." Thousands of such GT facilities around the world would thus be an essential means of eliminating and reversing the carbon emissions causing climate change.

GT works economically: It is a market-based approach that creates opportunities for profit rather than imposing costs. The carbon that GT facilities extract from the air can be used, and sold profitably for industrial purposes including plastics, building materials, bio-fertilizers, biofuels, greenhouses, desalinization of water and making carbonated beverages as well as the current fossil based carbon chemicals and pharmaceuticals.

Global Thermostat's technology, being tested at a demonstration site in Silicon Valley, can remove carbon dioxide from the air, potentially undoing decades of damage to the planet's climate. We envision a day when tens of thousands of CO2 vacuum cleaners are at work around the world removing CO2 that we previously emitted.

A Global Thermostat DAC module can extract CO2 from the air anywhere or its flue gas Carburetor can draw in fumes directly from a power plant. Inside, steam and sorbents extract CO2 from the air. When attached to carbon-emitting power plants, the company's technology could turn those plants into "carbon negative" factories that remove more carbon from the air than they emit. The process is mostly powered by the power plant's residual heat.

Global Thermostat's strategy is to tie carbon extraction to its profit potential rather than making it only about save-the-world altruism. The carbon captured is in a pure enough form that it may be sold at a profit, for industrial uses including plastics manufacturing, bio-fertilizers, biofuels, greenhouses, desalination of water and making soda pop fizzy. Global Thermostat has been setting up deals to provide CO2 capture systems for many of these applications already.

The UN Paris Agreement

After months if not years of preparation, and two weeks of intensive negotiations, the Paris COP21 climate conference held in late 2015 produced the Paris Agreement' hailed by world leaders as "a turning point for the world," signifying the end of the fossil fuel era. With no time lost, much of the news industry responded in a similar fashion, describing the agreement as the first legally binding global climate deal representing "the best chance to save the planet."

Unfortunately, these hopeful statements are not supported by the facts. The first legally binding international agreement in climate change was the Kyoto Protocol when it became international law in 2005. In contrast with it, the Paris Agreement has essentially no mandatory elements, except for the disclosure of intended nationally determined contributions (INDC) which are voluntary and do not suffice to meet even half of the targets of the Agreement. Furthermore, the Paris Agreement requires no action for at least 5 years. Overall, the Paris Agreement includes elements of previous agreements and scales up the hopes and ambitions from the critical previous agreement the Kyoto Protocol by including all nations; it is a statement of agreement about the change problem and of hope about solutions, but without any action plan.

The four Paris Agreement articles

The conclusion from the 2014 5th Assessment Report of the IPCC is that in addition to drastically reducing emissions through mandatory limits and adopting clean energy systems, it is now imperative that we utilize negative carbon technologies to remove existing carbon dioxide from the air. And now for the first time a major international agreement, the Paris Agreement, warts and all, contains not one but four articles referring to the necessary carbon removals that can transform everything.

"Carbon removals" or "carbon negative technology" were included as part of the official "mitigation actions" in Articles 4.1, 4.13 and 4.14 of the Paris Agreement. Both rich and poor nations are obliged to report carbon removals as part of their mitigation actions reported in the COP21, Intended Nationally Determined Commitment (NDCs) , going forward.

The developed nations have pledged to "provide," "take the lead," and "scale up" finance for developing nation's mitigation in Articles 9.1 and 9.4 of the Paris Agreement, and this is defined to include carbon negative technology or carbon removals. Therefore, carbon negative technologies such as those employed by Global Thermostat in Silicon Valley, California are well positioned to help since removals must be reported and can be funded under the provisions for mitigation.

Why does this matter? How can we use Global Thermostat Technology and other DAC technologies to use the leverage that these articles provide? To do this one needs to understand the whole picture

Because the pact agreed to in Paris December 12, 201 5 by nearly 195 nations is voluntary, it has no teeth. Indeed, the agreement is bound to nothing and no action is to be taken until 2020. Yet the four articles that we helped to introduce can take a huge difference to the climate change crisis. They contain the seeds of the entire solution, and will precipitate a global transformation of the world economy that is needed for resolving climate change.

This comes through an important new provision in the Paris Agreement to hold "the increase in the global temperature average to well below 2C above pre-industrial levels" which has been called dangerous equivocation". Again the only mandatory provision in the Paris Agreement is for nation to provide reports on the progress of their Intended Nationally Determined Commitments (INDC), whatever they may be, starting in 2020. Observe that even if the lNDC were mandatory - which they are not – all together they do not suffice to reach 50% of the carbon emission reductions in time to implement the Paris Agreement strategy of no more than 2C further temperature increase this century. This is one reason the Paris Agreement also acknowledged the need for negative emissions.

Furthermore, there aren't any mandatory payments in the Paris Agreement to help poor nations develop clean energy technologies, nor to mitigate the damages caused by climate change on poor nations, when the damage was historically caused by rich nations. But the four new articles (4.13, 4.14, 9.1 and 9.4) can turn things around. To see how, we need to show how to go from failure to success.

The worst failure of the Paris Agreement as already mentioned: it is the lack of mandatory emissions limits on the signatory nations, which are necessary for the carbon market to operate. What is traded in the carbon market is the right to exceed one's mandatory limits. With no mandatory limits, there can be no carbon market. The entire world is clamoring for a "price on carbon": this is the carbon market. Even the six largest oil and gas companies in the World publicly supported a price on carbon (Including Shell, BP, Statoil, Total and Exxon Mobil). Yet the Paris Agreement undermines the very foundation price on carbon by requiring no mandatory emission limits. "

How can Global Thermostat Technology and the four new articles help recover mandatory emission limits that are needed for the successful functioning of the carbon market? With carbon negative technologies, also called carbon removals, both the rich and the poor nations can and will accept conditional mandatory emission limits, from which a similar impact to mandatory limits will arise.

How this happens is shown below. And with mandatory emissions the carbon market can function and can make funding available to implement carbon removals. To make all this possible carbon negative technologies must be economically viable in removing CO2 from air and make it into goods and services that trap it on planet earth.

We can capture CO2 in the atmosphere and transform it into profitable goods and services, while cleaning the atmosphere. These markets are, or can be, large enough to absorb all the CO2 that humans emit into the atmosphere today, about 32 gig tons/year. It also creates jobs and can stimulate a period of prosperity as has been the case in the past when making major shifts to new economic opportunities.

We can even create carbon negative power plants most effectively by using the low temperature heat from renewable energy sources such as solar , geothermal and nuclear power plants and thus tum the energy sector into a carbon sink, cleaning the atmosphere of C02 and enabling the Paris Goal just mentioned: keeping temperature rises below 2C.We are effectively closing the carbon cycle just like nature does.

What Are We Waiting for?

A key factor to make this real is a technology that can implement carbon negative solutions, namely carbon removals, in an economically viable way. As mentioned previously there are now carbon negative technologies in Silicon Valley, by Global Thermostat, that are operating at SRI, that offer a solution to the greatest threat facing the future. DAC is a disruptive technologies for obvious reasons.

In terms of global policy, to implement this in a scale that matters require that we accept conditional mandatory emission limits and reactivate the carbon that is based on mandatory emissions and was already trading $175 billion year by 20 1 l. The funding from the carbon market would suffice to implement and scale up carbon removal around the World, as the IPCC requires, for example through carbon negative plants that clean the atmosphere while they produce.

Why did the Climate Fund sever the connection with its very source of funding, the carbon market of the Kyoto Protocol, which can offer enough funding for the solution to climate change? This is for the same reason that the Paris negotiations ended in an agreement with no teeth. The reason is the long standing insistence of the US Congress -through its venerable and unanimously voted Byrd-Hagel Act in 1996 of no mandatory emissions limits. A structure like the-Clean Power Fund - can use the funding from the carbon market of the Kyoto Protocol, which offers enough funding ($200 billion/year) to resolve the climate change problem.

Within the Paris agreement there is support for "carbon negative technologies" such (as those of the Silicon Valley) Global Thermostat a company we created. This and similar technologies can build "carbon negative power plants" that are profitable, and provide energy for development and poverty alleviation in poor nations while cleaning the atmosphere as required by the IPCC to avert catastrophic climate change.

The carbon market suffices to fund this effort, and will do so once we extend the mandatory emission limits: it can fund the removal of carbon from the atmosphere that is needed to avert climate change. The Green Climate Fund is all we have so far, and it has rather limited funding, as it has no identified source of revenues. But is the most reliable source of funding for clean technology.

The carbon market can only operate if there are legal limits on carbon emissions on the nations that trade in the carbon market. In an apparent reversal, carbon negative technology "carbon removals" -can help achieve this goal. The carbon market can fund carbon removals, and carbon removals can help implement the carbon market This is a self-implementing positive cycle that augers well for the global climate.

Many developing nations have expressed their interest and would accept conditional emission limits. They can be compensated implementing the limits with the newest technologies. For the rich nations, mandatory limits can be contingent on the implementation being economically feasible, costing less than the price obtained by selling the CO, removed from the atmosphere and even making profits. The combination of conditional carbon limits for the rich and poor nations would suffice for the carbon market to work.

And the CDM, which draws funds from the Carbon Market, can then offer the $200 billion each year that is needed to fund the Green Fund, as defined above. The result is to implement carbon removal that we now know are needed to avert catastrophic climate change. Let's do it.

More information

www.globalthermostat.com

USGS studies groundwater sampling

Scientists at the U.S. Geological Survey and their partners have completed a comparison study of deep-groundwater sampling techniques to provide guidance on the best available methods to accurately reflect the effectiveness of the carbon dioxide storage.

Accurate monitoring, including tracking important changes in groundwater chemistry and detecting any carbon dioxide leakage, is necessary to evaluate how the carbon capture is working.

The results of a recent comparison study by the USGS and partners at the Electric Power Research Institute and Lawrence Berkeley National Laboratory demonstrate the difficulty of preserving dissolved gases in groundwater samples, particularly in the form of dissolved carbon dioxide. Loss of CO2 causes a decrease in acidity and the precipitation of minerals dissolved in the water, changing the chemistry of the sample.

Collecting groundwater from a well that goes thousands of meters below the surface of the Earth has many challenges. The temperature and pressure differences between surface and depth are dramatic, and changes in these conditions can cause samples to lose dissolved gases, such as CO2, and minerals can precipitate causing chemical changes in the sample.

The sampling of deep groundwater is an important part of many projects, including monitoring and verification of deep groundwater during carbon storage and exploration of geothermal energy resources. A newly completed research paper, published in the International Journal of Coal Geology, details the results for a variety of chemical constituents from deep groundwater samples collected using four different sampler types.

JJ Thordsen (USGS) and a wireline operator retrieving downhole vacuum sampler from a characterization well near a CO2 injection well at Citronelle oil field, Alabama. U.S. Geological Survey,Public domain

The four sampling methods used in the study are gas lift, electric submersible pump, a downhole vacuum sampler, and a U-tube. Gas lift injects pressurized gas into the well, reducing the density of the groundwater, causing it to flow from subsurface pressure. An electric submersible pump is lowered into the well and pushes fluids to the surface. A down-hole vacuum sampler is a tool that is lowered into the well with a thin wire cable and consists of a sample bottle with locking valves and a timer.

The U-tube, designed and built by researchers at Lawrence Berkeley National Laboratory is a fixed loop of narrow stainless steel sample tubing extending from the surface to the sampling depth coupled with a pressurized source to drive the groundwater sample through the tubing.

Among the four sampling methods tested, the down-hole vacuum sampler and U-tube system, both of which can maintain the pressure at which the sample is collected, perform best at preserving sample integrity until an analysis can be done. Although the effects of sampling devices on sample chemistry are well known in relatively shallow groundwater studies, this study shows a more extreme version of some of these effects resulting from the greater temperatures and pressures associated with deep sampling.

JJ Thordsen (USGS) and a wireline operator retrieving downhole vacuum sampler from a characterization well near a CO2 injection well at Citronelle oil field, Alabama (©USGS)

The importance of cleaning the well before sampling was also shown in the study, as contamination by fluids left over from well drilling or maintenance was evident in some samples. Although the gas lift method substantially affected groundwater chemistry, it was essential in moving a large volume of groundwater to clean the well.

This research was carried out at the Citronelle injection site in Alabama, which is part of the Southeast Regional Carbon Sequestration Partnership Anthropogenic Test project, an integrated pilot project for carbon capture and storage that is funded by the United States Department of Energy and managed by the Southern States Energy Board in partnership with Southern Company, the Electric Power Research Institute, and Advanced Resources International, Inc., and the oil field is operated by Denbury Onshore, Inc.

Published in the International Journal of Coal Geology, the full report, "Comparison of geochemical data obtained using four brine sampling methods at the SECARB Phase III Anthropogenic Test CO2injection site, Citronelle Oil Field, Alabama," by Christopher Conaway and others, is available online.

More information

www.usgs.gov

Texas CO2 capture demonstration project hits 3M metric ton milestone

On June 30, 2016 Air Products successfully captured and transported, via pipeline, its 3 millionth metric ton of carbon dioxide to be used for enhanced oil recovery.

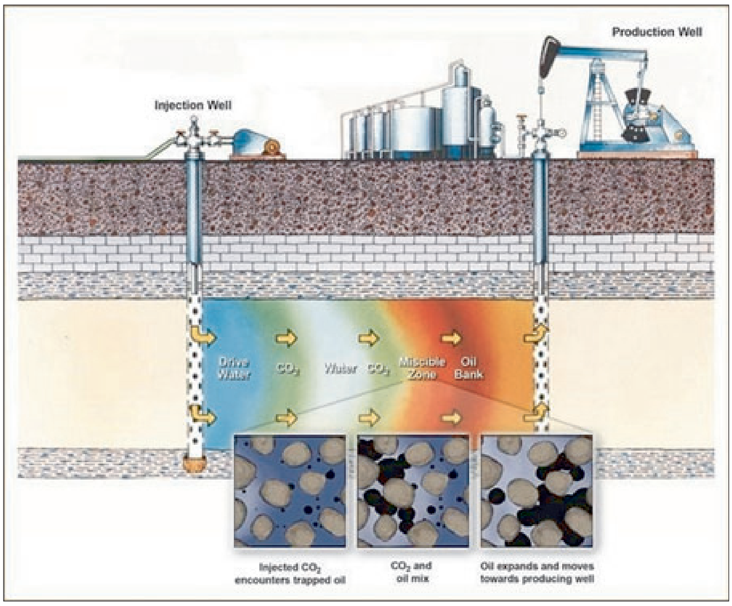
This achievement highlights the ongoing success of a carbon capture and storage (CCS) project sponsored by the U.S. Department of Energy (DOE) and managed by the National Energy Technology Laboratory (NETL).

The project demonstrates how a gas separation technology called vacuum swing adsorption can be implemented into an operating facility. The technology is being used at a hydrogen production facility in Port Arthur, Texas, to capture more than 90 percent of the CO2 from the product streams of two commercial-scale steam methane reformers, preventing its release into the atmosphere.

In addition to demonstrating the integration of Air Products' vacuum swing adsorption technology, the project is also helping to verify that CO2-enhanced oil recovery (CO2-EOR) is an effective method for permanently storing CO2. CO2-EOR allows CO2 to be stored safely and permanently in geologic formations, while increasing oil production from fields once thought to be exhausted.

The CO2 captured from the Port Arthur facility is being used for EOR at the West Hastings Unit (oilfield) in southeast Texas. Injected CO2 is able to dissolve and displace oil residue that is trapped in rock pores. It is estimated that the West Hastings Unit could produce between 60 and 90 million additional barrels of oil using CO2 injection.

In total, projects sponsored by the U.S. Department of Energy have captured and securely stored more than 12 million metric tons of CO2, equivalent to taking more than 2 million cars off the road for a year. Investing in projects and technologies, such as Air Products', are critical to paving the way for more widespread use of CCS technologies.



Schematic of the CO2-EOR process

The Air Products project is supported through DOE's Industrial Carbon Capture and Storage (ICCS) program, which is advancing the deployment of CCS technologies for industrial sources at commercial and utility-scale. CCS innovation is important to not only reduce future greenhouse gas emissions from power plants, but it also helps to ensure that U.S. industries are powered in the most efficient, sustainable, and clean way possible, while continuing to use America's long-standing and abundant energy resources.

More information

www.airproducts.com

More news from the U.S.

GE joins MIT low carbon energy centers

energy.mit.edu

GE will participate in the MIT Energy Initiative and one if its focusses will be CCS.

Achieving a future in which everyone has access to affordable, plentiful power — while decarbonizing global energy systems to address climate change and protect our environment — takes numerous sustained, collaborative efforts across all sectors around the world.

The MIT Energy Initiative (MITEI) and GE have committed to work together on solving these challenges as GE becomes a Sustaining Member of MITEI with $7.5 million in funding for advanced technology R&D over a five-year period.

As part of its membership, GE will engage with four of MITEI's Low-Carbon Energy Centers, focusing on solar energy; energy storage; electric power systems; and carbon capture, utilization, and storage.

On Tuesday, MITEI and GE launched their collaboration with a half day of meetings on MIT's campus to discuss current MIT research and technology advancements, and how GE's global businesses can work with MITEI to move these technologies toward commercialization and adoption.

In her opening remarks, Maria Zuber, MIT's vice president for research, discussed MIT's Plan for Action on Climate Change and the importance of engagement with industry. "With research collaborations that are multidisciplinary and multisectoral, like the Low-Carbon Energy Centers, we can identify the economic, social, political, and regulatory barriers that prevent good technologies from scaling, and then together we can develop strategies for surmounting those barriers," she said.

"Working closely with industry to solve practical problems in the real world has been a hallmark of MIT's approach for well over a century. We are delighted to have this chance to work with GE," Zuber added.

DOE research featured in journal special issue

edx.netl.doe.gov/nrap

A special issue of the International Journal of Greenhouse Gas Control features some of U.S. Department of Energy CCUS work.

A compendium of research generated by the Energy Department's National Risk Assessment Partnership (NRAP) team over 6 years of collaboration, the special issue comprises 60 peer-reviewed publications which, taken together, represent a significant contribution to the state-of-knowledge on long-term risks of geologic CO2 storage (GCS).

Although the IJGGC features a number of special issues centered upon meetings or topics, this is the first time that a special issue has been focused around results from a research team. The articles detail critical advancements in scientific understanding, risk assessment methodology, and computational tool development related to full GCS system performance.

NRAP brings together scientists and engineers from across the U.S. Department of Energy (DOE) national laboratory complex to improve understanding of environmental risk performance of geologic CO2 storage. The partnership applies DOE's unique core capabilities in the science-based prediction of critical behaviors of engineered-geologic systems.

Release of the IJCC special issue coincides with the completion of NRAP's first phase of research, which has resulted in the generation of first-of-kind scientific data, methodologies, and simulation tools to support quantitative assessment of environmental risks associated with industrial-scale GCS.

NRAP is now transitioning into a second phase, in which the risk-assessment methodologies and tools developed during phase 1 will be applied to real-world CO2 storage sites, and new tools and findings will be generated to help effectively manage carbon-storage operations. A significant focus will be how to strategically monitor a geologic system to reduce uncertainty in its performance and build confidence that CO2 is effectively and safely stored.

DOE invests $28m for cleaner fossil fuel power

fossil.energy.gov

The U.S. Department of Energy (DOE) has selected 14 research and development projects to advance energy systems that will enable cost-competitive, fossil fuel–based power generation with near-zero emissions.

The new projects, which span 11 states, will accelerate the scale-up of coal-based advanced combustion power systems, advance coal gasification processes, and improve the cost, reliability, and endurance of solid oxide fuel cells. The total award value of the projects exceeds $36 million, which includes a federal investment of more than $28 million and recipient cost-sharing of $8.4 million.

Funding for the new projects is provided by DOE's Office of Fossil Energy (FE). The projects will be managed by FE's National Energy Technology Laboratory. The selected projects will support DOE's Advanced Combustion Systems Program, which is developing efficient and economically attractive combustion systems that generate electricity with near-zero emissions.

DOE invests $11.5 Million in geothermal energy and CCS

fossil.energy.gov

Eight new research and development projects to receive a total of $11.5 million in federal funding.

The funding is being awarded under the DOE's Subsurface Technology and Engineering Research, Development, and Demonstration Crosscut initiative. The new projects are focused on furthering geothermal energy and carbon storage technologies, and will be funded by the Office of Energy Efficiency and Renewable Energy's Geothermal Technologies Office (GTO) and the Office of Fossil Energy's (FE) Carbon Storage program.

"The projects selected today will advance our ability to store captured carbon pollution from the burning of fossil fuels and improve our understanding of renewable geothermal resources – both of which will help us achieve our nation's climate and clean energy goals," said DOE's Under Secretary for Science and Energy Franklin Orr.

"The announcement of these selections also underscores the importance of the crosscutting initiatives that Secretary Moniz has encouraged throughout DOE. Sharing expertise and experiences across the Department is helping us make progress on challenging energy science and technology that demand expertise across the science and engineering disciplines."

Many opportunities exist to use the rocks beneath the earth's surface to improve the way energy is used – including next generation geothermal energy, safely storing greenhouse gases that are contributing to climate change, mitigating the impacts of fossil energy development, and nuclear waste storage and disposal.

Across those varied challenges, the Subsurface Crosscut addresses a number of common technical issues. In particular, it plans and implements research, development, and field demonstrations emphasizing four pillars: Wellbore Integrity, Subsurface Stress and Induced Seismicity, Permeability Manipulation, and New Subsurface Signals.

The new projects fall under two objectives: (1) deploy and validate prototype carbon storage monitoring, verification, and accounting (MVA) technologies in an operational field environment, and (2) identify and validate new subsurface signals to characterize and image the subsurface, advancing the state of knowledge in geothermal exploration.

Projects under the first objective are required to deploy technologies or techniques associated with near-surface and/or subsurface monitoring at a large- or commercial-scale site for validation.

Reducing carbon emissions as a business strategy

With a number of international initiatives to reduce global CO2 emissions gaining momentum, the pressure on companies to reduce emissions is mounting. Companies can harness advances in connected measurement technology to drive new revenue streams during the necessary transition from waste to capture of CO2. Lana Ginns, Marketing Manager at Fluenta, discusses the central role of accurate measurement technology in an effective energy management scheme.

After COP21 it is likely that operators will have to monitor and reduce their flaring gas emissions - they should take the opportunity to turn waste into revenue

An International Energy Agency (IEA) report, 'CO2 Emissions from Fuel Combustion Highlights 2015' estimates that more than 40% of CO2 emissions come from the power sector, with a further 20% resulting from large-scale industrial processes such as chemicals production.

While global demand for fossil fuels is likely to remain strong – particularly in developing countries – carbon capture and storage (CCS) is often the most practical way of reducing CO2 emissions in high-emission industries. In many cases, it is the only way.

A lack of governmental support

Official advisers on climate change to the UK government – the Committee on Climate Change (CCC) – and the United Nation (UN) climate panel, have both issued warnings that unless CCS is adopted, the cost of tackling climate change will double. While the cost of CCS is often cited as a barrier to adoption, companies and governments need to consider how to make implementation of CCS technology an economically viable option.

This reluctance from both sides was demonstrated when the UK government cancelled a billion-pound competition for CCS technology days before the landmark COP21 climate change conference in Paris in November 2015. Drax, the company that operates Drax Power Station, the biggest power station in the UK and the frontrunner to receive the investment, abandoned its £1 billion CCS installation because of the government's reduction of subsidies for renewable energy. Following the cancellation, the National Audit Office (NAO) said there is now no viable way to achieve industrial emissions reductions in the near future.

The flaringly obvious solution

Companies need to take the initiative to reduce carbon emissions, with or without support from government. Global agreements should give companies the confidence and incentive to invest in technology to accurately measure, manage, reduce, and ultimately eliminate, routine CO2 emissions from flaring and venting. While gas flaring is used for safety reasons, many facilities use it as the main method of disposal due to a lack of infrastructure required to capture, store, and monetise the gas.

With initiatives like COP21 and the World Bank's Zero Flaring by 2030 drive, it is extremely likely that new legislation on the measurement and monitoring of gas volumes will soon be introduced to make it mandatory for companies to practically manage legally binding, large scale reductions. Companies should therefore be investing now to meet this trend head on.

Companies need to work towards eliminating ongoing flaring within existing operations and must ensure that new developments incorporate gas utilisation solutions that will avoid routine gas flaring or venting. Ultrasonic flow meters have a significant part to play in this, as accurate flow measurement will be vital not only in managing flaring reduction and ensuring compliance with any associated regulation, but will also help to inform strategy and planning once widespread gas capture and storage solutions are in place. Management is crucial to this process, and unless companies can accurately measure, effective management is impossible.

In Kazakhstan, a joint venture of Chevron, ExxonMobil, Kazmunaigaz and LukArco has eliminated gas flaring emissions in the giant Tengiz oil field by 94%. Azerbaijan has cut flaring by 50% in two years, Mexico by 66% and Kuwait now only flares 1% of its gas. Other countries, including Qatar and the Democratic Republic of the Congo, now use large volumes of previously wasted gas to generate electricity.

It is the highest gas flaring countries that will struggle to implement the changes. Many companies currently flaring excess gas simply estimate the volume of their emissions based on factors such as pipe size and pressure levels. More focus must be given to accurate measurement, using dedicated ultrasonic flow meters, before management and reduction are a realistic possibility.

Many operators still flare gas - if companies invest in new technologies to measure, monitor, and capture excess gas, gas flaring operations can be monetised (Image ©Fluenta)

Increasing revenue while reducing emissions

The compliance environment is poised to become tighter and even more complex and companies need to be looking at gas capture as a strategic business benefit, rather than regulatory requirement. The last few years have been traumatic for the Oil & Gas Industry, with prices reducing by more than two thirds. Operators need to get creative to maintain revenue.

If companies invest in new technologies to measure, monitor, and capture excess gas, gas flaring operations can be monetised. In doing so, companies will be well positioned to meet changes in the global regulatory landscape. By making flare gas capture more economical, companies can increase their revenues and maximise their profitability, while at the same time significantly reducing their carbon emissions.

Methane capture is far more cost-effective than it once was and offers operators the opportunity to create solid energy management schemes, including re-directing excess gas to power operations. Developments in mobile gas capture technology have enabled gas capture to be utilised at smaller sites. This is particularly relevant with the huge growth in hydraulic fracturing operations (fracking), which are often smaller and more short term.

While long-term gas capture technology generally includes the installation of permanent gas pipelines, GTUIT's solution takes the form of mobile gas capture and natural gas extraction units – about the size of a semi-trailer – which can be deployed quickly and easily, even in remote locations. In partnership with the Hess Corporation, GTUIT recently installed 15 of these units at oil well sites in North Dakota, one of the highest gas flaring regions in the world that falls under 'economic' reasoning.

The mobile gas capture units are gathering around 35,000 gallons of Natural Gas Liquids every day, and the positive impact on the environment has already been significant. By capturing the gas rather than flaring, the 15 mobile units have prevented the release into the atmosphere of around 55,900 tons of carbon dioxide and 17,100 tons of volatile organic compounds.

The North Dakota project has drawn considerable industry interest and serves as a prime example of what can be achieved with the appropriate application of technology. It has also netted the contributing companies a prestigious excellence award from the World Bank Global Gas Flaring Reduction Partnership.

Similar mobile gas separation and conditioning applications have been developed by other companies – such as Pioneer Energy's Mobile Alkane Gas Separator (MAGS) system. Solutions such as those presented by GTUIT and Pioneer Energy have the potential to offer a 'holy grail' – benefiting the environment, providing an additional revenue stream from the sale of captured gas and contributing to on-site energy efficiencies. The mobile units allow gas captured to be conditioned and used directly to power engines and generators on-site, in many cases delivering direct savings in comparison to existing diesel or dual-fuel systems.

Accurate measurement technology is the first step towards the large-scale capture of gas. Many sites still estimate emissions and this level of inaccuracy cannot support the implementation of gas capture technology – whether mobile or fixed. Whether excess gas is being flared or diverted to a capture mechanism it is crucial the operator knows exactly how much gas it is releasing. The unpredictable nature of gas extraction means that flow measurement needs to be able to manage wide fluctuations in the velocity of gas, different atmospheric conditions and changing compositions of the gas.

Smarter operations

Advances in connected infrastructure – the Internet of Things (IoT) – mean operators can now collect and analyse emissions data remotely. Where previously engineers would need to be present on-site to physically download data, connected meters offer far greater visibility, huge cost savings and will enable better management and optimisation of emissions in large scale operations.

When real-time data is fed into Cloud-based software such as continuous emission monitoring systems (CEMS), organisations can collect, record and report data remotely and in real-time. The software is run on the central server of the business and it is therefore not necessary to store and run the software on a machine on-site, reducing cost and the necessity of having a human operator on-site to manage the hardware and associated data. Additionally, the data is stored securely on a remote server and is not dependent on the health and reliability of an on-site machine.

The operator can then access and analyse the data using a variety of devices, providing they are connected to the internet. With internet connectivity available almost everywhere, businesses can access the real-time data feeds of remote assets from multiple devices, anywhere in the world.

The combination of accurate, real-time information on remote assets and cloud technology can have a significant positive impact on moving high-flaring industries from a monitoring approach to a management approach. It enables companies to access information on extreme events, and make strategic decisions based on historic data. By using cloud technology to record gas flaring, companies can build a better picture of trends over time and utilise this information to derive valuable insight to inform business strategy.

Real-time data can be used to create a competitive advantage. Data retrieved from different sites can be compared to more effectively manage the flaring process – site to site, country to country, or process to process – enabling continuous improvement over time. Best practice can be taken from top performing (low emission) sites and implemented across the entire business operation.

Conclusion

The ability to access diagnostic information remotely is already widely used in the utilities sector where, for example, remote assets have been controlled by telemetry for many years to manage a number of tasks. When applied effectively to emissions, remote asset management through connected infrastructure has huge potential to revolutionise operations in high-flaring industries like Oil & Gas and chemicals production.

While the ability to operate without any personnel is still some way off, any reduction in the number of personnel needed will soon add up to considerable cost savings. In turn, this frees up resources to implement gas capture technology, and energy management plans that reuse excess gas to power operations. With increasing pressure to optimise business strategy under financial constraints while at the same time reducing emissions, the visibility offered by connected flare meters can help companies streamline efficiencies across whole operations and support the move towards large scale capture and storage solutions.

More information

www.fluenta.com

CCSA-CSLF Joint Workshop – "CCS Post-Paris: Realising Global Ambitions"

On the 29th June 2016 the Carbon Capture & Storage Association (CCSA), in collaboration with the Carbon Sequestration Leadership Forum (CSLF) held a joint workshop as part of the annual CSLF meetings, which were this year hosted by the UK from the 27th to 30th June.

The following is taken from a CCSA report on the meeting. The report summarised the meeting as follows:

Key themes of the workshop

1. Developing an investable business model

The need to change the business model for CCS and develop an investable business model emerged a number of times throughout the day. A number of presenters raised the challenge of an appropriate risk-reward balance across the chain and the need to ensure sufficient financial guarantees across the chain.

For a company, the business model needs to reflect the fact that benefits must exceed costs and that for a storage company in particular, there is a pre-operational period and a post-closure period where no revenue is forthcoming. This 'overhang' needs to be addressed to make any business model successful. It was clear that different business models are needed for each part of the chain and that business models also need to be tailored to projects. Governments will also need to do their part and develop regulatory frameworks that can accommodate part of the risk.

2. Solutions - break the chain and public-private partnerships

Considering the options for how to move forward with CCS, one particular phrase was coined; the need to 'break the chain'. A number of presenters essentially recommended that the support required for capture needs to be considered separately to the support required for transport and storage infrastructure, due to the fact that capture and infrastructure represent inherently different types of projects and therefore suit different business models and incentives.

Other potential solutions included developing projects via a public-private partnership approach.

Session 1: The role of CCS post-Paris

The workshop began with two introductory presentations; from Philippe Benoit (International Energy Agency) and Myles Allen (Oxford University). Both presentations looked at the new landscape following the Paris Agreement and the need to revise models and scenarios (e.g. the IPCC Assessment Reports) in line with the new 1.5°C goal. The desire to reach net zero carbon emissions was also discussed.

Both presenters emphasised the importance of CCS to meet the 1.5°C and net zero emissions goals - in particular, it was pointed out that CCS has an advantage as it provides flexibility to countries on how to meet the Paris Agreement. This is especially the case for bio-CCS (BECCS) which will become increasingly important as a negative emissions technology, and will again provide valuable flexibility and could possibly offset harder-to-decarbonise sectors such as aviation. The presenters also stressed the need to move CCS away from a singular focus on power generation and look at other sectors such as industry and Enhanced Oil Recovery.

Session 2: Preparing for deployment

This session focussed on the UK and global storage potential, as well as experiences in implementing carbon capture readiness requirements in the EU and beyond. In terms of storage capacity, the presentations concluded that in the UK and globally there is a substantial storage resource - the UK Storage Appraisal Project found that there is enough data to start the UK CCS industry and that there are no technical barriers to the 5 main storage sites that were investigated. From a global perspective, the data is extremely variable depending on the country and whether they have carried out any national storage assessment.

A presentation then followed on experiences in implementing carbon capture readiness (CCR) in Europe and beyond. The first presenter (from the EU Commission) concluded that the CCS Directive is currently fit for purpose and no revision is required yet. In terms of CCR, it was found that the UK has the most practical experience, with detailed guidance issued by the Department for Energy and Climate Change (DECC) as well as regular monitoring reports. However, some challenges remain.

Looking beyond the UK and Europe, there is relevant CCS legislation in countries such as the U.S., Canada, Australia, China and Norway. In conclusion, to comply with CCR in Europe, more effort is needed to increase storage readiness and identify locations of potential clusters. These would also be valuable lessons outside the EU, particularly for emerging economies looking to utilise CCS as part of their emissions reduction strategies.

Session 3: Hubs, clusters and sharing infrastructure

A presentation on the North Sea Basin Task Force - a Government-to-Government initiative involving the UK, Netherlands, Gemany, Norway, Belgium and others - kicked off this session with a focus on how to develop European CCS infrastructure and ensuring the first EU CCS projects are expandable with the potential to build upon. A strategic regional plan is needed to ensure coordination and deliver projects of common interest.

A panel discussion then followed with brief remarks from the ROAD/Rotterdam hub, the Teesside Collective cluster and the Scottish CCS perspective. The Rotterdam project, although a small hub, is aiming to extend to other parts of Holland (starting with The Hague). The idea is to use the Rotterdam hub to also provide district heating to cities as well as looking at other uses for heat.

Turning to the Teesside Collective, this project has been developing an industrial blueprint that can be replicated to other areas. In terms of next steps, it was emphasised that a business case and funding proposition is now needed, as well as a strong national policy. It is likely that moving forward, smaller-scale projects will be prioritised over large-scale ones.

Finally, the panel heard from Scottish Enterprise - they are currently developing an industrial CCS roadmap, also looking at smaller-scale projects initially. The presenter emphasised the need for public-private partnerships, the need to de-risk storage and the need to persuade Governments of the importance of CCS to increase interest and provide funding.

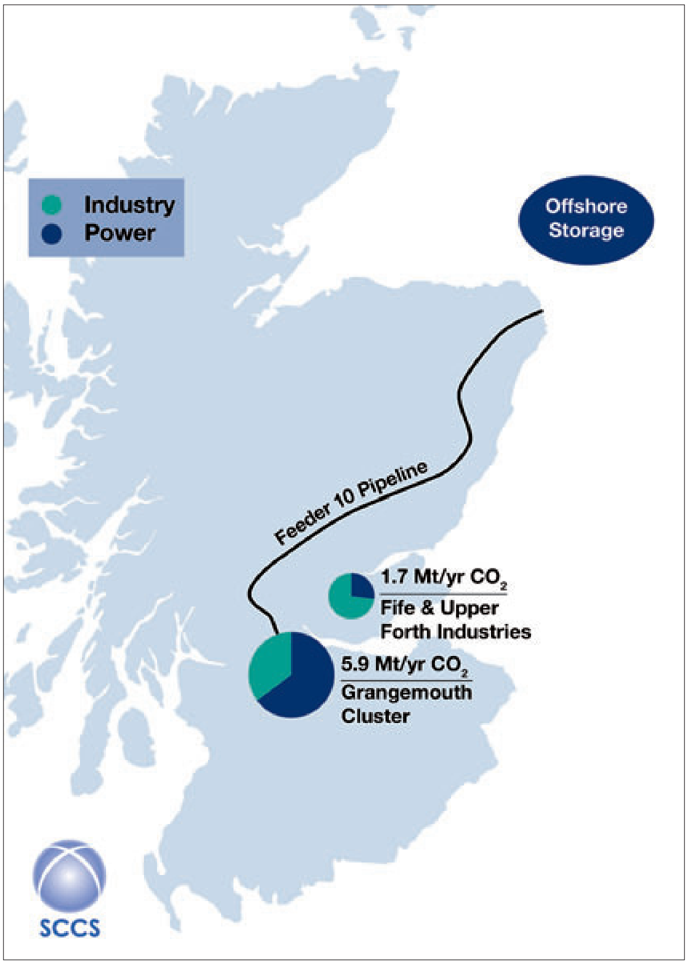
Session 4: Fresh perspectives on CCS

The CCSA gave the first presentation in this session on the new CCSA report “Lessons Learned - Lessons and Evidence Derived from UK CCS Programmes, 2008-2015”. The report sets out a number of positive lessons; both CCS competition projects would have delivered the outcome and the key barriers to delivering the projects were commercial, not technical.

A number of challenges also emerged from the report including the need to solve cross-chain risk, making CO2 storage an attractive investment proposition and the negative impact policy changes can have on private sector investment appetite.

ZEP gave the next presentation on the need for a ‘market maker’ to develop an appropriate business model for CCS. The role of CCS hubs was emphasised as being key to developing cost-effective CCS projects, and the importance of politically supportive countries/Governments or regions was also raised.

The next three presentations looked at the case for shipping CO2, US DOE lessons on brine extraction and storage and the H21 Leeds City Gate hydrogen project. On shipping, the presentation pointed out that whilst there are some challenges with shipping (e.g. pressure) there are also a number of benefits such as intermediate storage and direct injection.



Scotland’s industry clusters could reduce the cost of carbon capture and storage through shared infrastructure and re-use of existing pipelines (Image ©SCCS)

The US DOE summarised the results of phase 1 of the brine extraction and storage test, which has carried out a regional characterisation of the geological storage potential of northern U.S. and southern Canada. Finally, Northern Gas Networks gave a presentation on the H21 Leeds City Gate project, which proposes to convert the Leeds gas grid into a hydrogen network. This innovative project is receiving quite a lot of attention at the moment due to its ability for incremental rollout as well as being flexible and expandable.

Session 5: What can the CSLF do? Summary and Next Steps

The final session included concluding remarks from the CSLF Technical and Policy Group chairs and the CCSA. The CSLF representatives summarised current activities, including new task forces, a roadmap (which will be delivered at the CSLF Annual Meeting in October 2016) and the goal of making clear recommendations to the CSLF Policy Group.

The CCSA emphasised how much industry values engagement with the CSLF and pointed to the need to change thinking around CCS and look at the regional /bottom-up drivers for CCS.

More information

Download the full report:

www.ccsassociation.org

www.cslforum.org

CCS funding cancellation criticised by UK National Audit Office

A report by the National Audit Office (NAO) says that the cost of meeting UK climate targets could be £30 billion more per year.

The NAO report, "Sustainability in the spending review" says that the Treasury did not calculate the cost and impact of delaying CCS deployment before it cancelled the £1 billion CCS Competition. It estimates that the additional cost of the delay could be £30 billion annually by 2050.

"HM Treasury raised concerns about the merits of the carbon capture and storage competition given fiscal constraints, but neither DECC nor HM Treasury quantified the cost of delaying large-scale deployment of the technology," states the report.

The NAO will report on DECC's management of the CCS programme prior to the cancellation in another report later in 2016.

Dr Luke Warren, Chief Executive of the CCSA, commented:

"This report unequivocally shows that the full costs and impact of delaying CCS were not adequately considered in the run up to the cancellation of the CCS competition. Whilst HM Treasury judged that the competition was aiming to deliver CCS before it was cost efficient to do so, the Energy Technologies Institute has shown that a ten-year delay to CCS could add an additional £1-2 billion to consumers' bills every year throughout the 2020s."

"Despite the cancellation of the CCS competition, industry in the UK stands ready to deliver and the Government must now move forward and urgently develop a new and improved approach to CCS that delivers this essential low-carbon infrastructure for the UK economy - recognising the wider benefits of CCS to decarbonise energy intensive industries, power, heat and hydrogen."

"The new Department for Business, Energy and Industrial Strategy will be well-placed to deliver a more holistic and strategic approach to CCS and we look forward to building a constructive relationship with the Department."

Professor Stuart Haszeldine, Scottish Carbon Capture and Storage (SCCS) Director, said: "The Treasury's axing of the UK's CCS competition brought a great deal of criticism. It was a premature decision, made before the two preferred project bidders, White Rose and Peterhead, had even submitted their design studies. It also reflected a lack of understanding of the strategic value of CCS to the UK's climate ambitions as well as our perceived leadership on climate action globally.

"After the Paris COP21 climate agreement for advanced economies to become zero-carbon by 2050, it is clear that CCS is unavoidable. Yet, remarkably, that deal was struck just one week after the Treasury's cancellation decision. The lack of foresight or joined-up thinking across Government departments was baffling.

"Today's report by the National Audit Office reaches the same conclusions that previous analyses have shown – namely, that CCS has immense value across an entire economy. It is not about expensive electricity, it is about the sustainable use of fossil fuel wealth. It means the provision of low-cost, carbon-free heat, and a cleaner atmosphere worldwide.

"The development of a UK-based CCS industry also has the potential to maintain and grow the UK's workforces in process, chemical and manufacturing industries. Overall, CCS means meeting carbon targets and playing our part in protecting society and the environment from the worst impacts of global warming.

"This report is very critical of the Treasury's lack of success at working across departments to join up expenditure on the one hand with clear benefits on the other; in this case, clear cost savings in the long-term as part of decarbonising the UK's power, industry, heat and transport sectors.

"The cancellation of two well-developed CCS projects in 2015 has led to a collapse of industry interest in building projects in the UK. This will mean that, when projects are eventually built, the Government will need to pay more to convince industry investors that the UK can be trusted to deliver on its contractual promises. That is bad value for consumers, for industry and for the climate.

"Treasury decisions have a history of being made impatiently, where short-termism is unable to support fundamental change that requires many years of design evaluation, demonstration, confidence building and construction. This does nothing to help UK industries build new global successes in an outward facing global economy.

"Now, with the UK's decision to investigate leaving the European Union, developing and maintaining global expertise in science and technology design, consultancy and construction is more pertinent than ever.

"Energy is one of the biggest global markets. CCS is one part of that market, where UK Government support could boost innovation and invention to ensure that the UK becomes a natural exporter of CCS expertise and consultancy, not an importer.

"It is clear that, when making assessments of long-term infrastructure needs, such as CCS, the Treasury need to be more sophisticated in its assessment of value and less driven by simplistic calculations of near-term profitability.

"The transition of the UK into a low-carbon economy will not be achieved overnight, and investment from the Government over many decades and across multiple sectors is not an optional extra. It is essential."

More information

Download the full report from the UK National Audit Office

www.nao.org.uk

Projects and policy news

Australia invests $23.7m in CCS RD&D

www.industry.gov.au

AUD $23.7 million has been awarded to seven applicants under the Carbon Capture and Storage Research Development and Demonstration Fund (CCS RD&D Fund).

The CCS RD&D Fund provides funding for carbon capture and storage (CCS) projects with a particular focus on transport and storage. It supports the Australian Government's commitment to reduce the technical and commercial barriers to the deployment of large-scale CCS projects.

The Government hopes that these projects will also encourage industry investment in further deployment of CCS technologies. The seven projects selected include both industry and research institution-led projects.

The grants range in size from $693,450 to nearly $9 million and had to be matched at least dollar-for-dollar by grant recipients.

Building low-carbon bridges with Australia

www.imperial.ac.uk

www.csiro.au

Imperial College London is working with Australia's CSIRO to fund research and development of clean fossil fuels.

Carbon capture and storage (CCS) is considered by many to be one of the key technologies needed for a transition to a low-carbon energy sector. The latest collaboration between Imperial College London and the Australia-based Commonwealth Scientific and Industrial Research Organisation (CSIRO) will focus on further developing the technology to help meet ambitious climate change targets.

The collaboration will fund two new studentships to explore a solution where captured carbon can be stored in old underground oil and gas reservoirs. Once the oil or gas has been extracted from these pockets hundreds of metres underground it is hoped that they could be used as a storage site for carbon dioxide (CO2). The projects will look at how natural gas, oil and CO2 behave, and can be contained, in these empty reservoirs.

Each project will tackle a different side to the problem. The first will look at new approaches to monitoring the behaviour of CO2 storage reservoirs using modified versions of techniques traditionally used in petroleum exploration by the oil and gas industry.

The second will use cutting-edge, non-invasive techniques to understand the interactions between natural gas, oil and CO2 in unconventional gas reservoirs, with a view to developing combined CO2 utilisation and storage (CCUS) technologies.

Together the projects will improve how we get the CO2 into the reservoirs and how we manage and monitor them once it is in there. Crucially, this work will be built around real-world scenarios, through CSIRO's involvement in Australia's CCS demonstrator projects, such as the Otway project on the South coast of Australia.

"These two shared studentships are an exciting step toward building a working relationship between CSIRO and one of the world's leading academic institutions in the CCS area. We are thrilled to be able to share our knowledge and links to our world-class carbon dioxide storage demonstration facilities with Imperial College London researchers as we welcome them and establish closer ties to our colleagues based in London," says Dr Patrick G. Hartley, Research Director, Oil Gas & Fuels, CSIRO.

These kinds of international collaborations demonstrate that open innovation can thrive in such environments. It allows the inclusion of global experts from NGOs, industry and academia and fosters closer links between the UK and Australia on many issues, including the deployment of CCS on a commercial scale.

Geoffrey Maitland, Professor of Energy Engineering at Imperial College London's Department of Chemical Engineering says: "At Imperial we have a highly active CCS research environment and this unique opportunity to take our research out of the laboratory and into the field is truly exciting.

Working with CSIRO also promotes knowledge sharing between likeminded researchers from different regional settings allowing a sustainable pathway for the development of CCS to be identified."

ExxonMobil will expand its collaboration with the university's Gulf Coast Carbon Center

energy.utexas.edu

ExxonMobil will expand its collaboration with the university's Gulf Coast Carbon Center

ExxonMobil will invest $15 million as a leadership member of The University of Texas at Austin Energy Institute to pursue technologies to help meet growing energy demand while reducing environmental impacts and the risk of climate change.

The joint research initiative will study transformational energy innovations, including integrating renewable energy sources into the current supply mix and advancing traditional energy sources in ways that improve efficiency and reduce effects on water, air and climate.

Research projects are expected to cover a range of emerging technologies and will take advantage of the university's capabilities in renewable energy, battery technologies and power grid modeling. Core strengths in advanced computing, environmental management and additive manufacturing may be applied to improve the efficiency of delivering traditional energy sources.

"The University of Texas at Austin has extensive experience and expertise in identifying innovative energy technologies," said Sara Ortwein, president of ExxonMobil Upstream Research Company.

"Our scientists and engineers look forward to collaborating with UT's faculty and students through the Energy Institute to develop breakthrough technologies that can help reduce emissions."

ExxonMobil will expand its collaboration with the university's Gulf Coast Carbon Center, a multidisciplinary group that has specialized in geological sequestration of carbon dioxide since 1998. This research will complement ExxonMobil's recently announced partnership with FuelCell Energy Inc. to advance carbonate fuel cell technology to enhance the affordability of carbon capture from power plants fueled by natural gas.

ExxonMobil has collaborated with more than 80 universities worldwide in researching breakthrough energy technologies. Last year, the company joined Princeton University's E-ffiliates Partnership, a corporate affiliates program administered by Princeton's Andlinger Center for Energy and the Environment. E-ffiliates fosters collaboration with industry in pursuing energy and environmental innovation.

ExxonMobil committed $5 million over five years, the largest financial commitment the program had received. In 2014, ExxonMobil became a founding member of the Massachusetts Institute of Technology Energy Initiative, investing $25 million over five years toward research and graduate-level energy fellowships.

CCS Forum report calls for increased funding into CCS deployment

www.icheme.org

CCS deployment must be progressed as an urgent priority if the world is to achieve the global warming limits identified in the Paris Agreement, a new report says.

Launched by the CCS Forum, the report urges policy-makers and governments to avoid focusing on the near-term targets at the detriment of long-term goals.

Written by the CCS Forum, a group of experts from academia, industry, and government supported by the Institution of Chemical Engineers (IChemE) Energy Centre, the UK Foreign and Commonwealth Office, the Royal Society of Chemistry and Imperial College London, the report was developed following a three day CCS Forum conference, held at the Royal Academy of Engineering in February 2016.

Focusing on the Paris Agreement, in which the world agreed to limit global warming to 2oC, the report identifies that 120-160 gigatonnes of carbon dioxide (CO2) will have to be stored until 2050. Positively, research findings from the CCS Forum experts show that the reservoirs to do this are available through oil and gas reservoirs, unminable coal seams and deep saline aquifers.

However, the report places significant importance on the need for funding and urgency if CCS is to help to tackle climate change. It also identifies ten priorities for CCS including focusing on £/MWh to measure impact, developing a whole systems approach to energy and infrastructure, and carefully evaluating the role of electricity markets.

The report comes after significant cuts to CCS were made by the UK government at the end of last year, including scrapping a ring-fenced budget of £1 billion. Today's report calls on policy-makers to concentrate on long-term goals, and not let targets be missed by focusing on short-term wins.

The CCS Forum Report was launched in London, UK at IChemE's offices on Wednesday 27 July, hosted by IChemE's Energy Centre Chair and Dean of the College of Engineering, Design and Physical Sciences at Brunel University London, Professor Stefaan Simons. The report was presented by its led-author Dr Niall Mac Dowell, also from IChemE's Energy Centre and Imperial College London, followed by a discussion with a panel of experts, an invited audience and online participants.

Professor Simons said: "The COP21 target of limiting the average global temperature rise to 1.5oC means that the decarbonisation of industrial emissions, from whatever process, must be significantly accelerated. We no longer have the luxury of prevarication. CCS offers an opportunity to decouple the use of fossil fuels from climate change."

"The CCS Forum report is an important step in the future prospects for CCS, as, for the first time, it suggests radical ways in which we can rethink the economic and technological development of the process, making it more attractive to investors and government decision-makers alike. Without such changes in perspective, we will not get past the barriers to deployment and, more importantly, we risk not meeting our carbon reduction goals in time to mitigate disastrous climate change."

Dr Mac Dowell stated that: "The ambitious targets set by COP21 in Paris are only feasible with the large scale deployment of CCS technology. Our report represents the views of leading CCS experts from around the world; including power and industry, capture, utilisation, transport and storage, and identifies the key research and development needs for this area for the coming decade. I hope this will provide a meaningful contribution to CCS cost reduction and help remove the final barriers to the deployment of this vital technology."

Also in attendance was The Carbon Capture & Storage Association's Policy Manager, Theo Mitchell, who said: "We welcome this report as a timely contribution to the ongoing discussions around the future of CCS. The UK Government has recently reiterated its intention to develop a new approach to CCS and we're looking forward to working with the Institute for Chemical Engineers and the wider academic community to help shape the future research and innovation agenda for this vital technology."

The Energy Research Partnership's Andy Boston, who took part in the report launch panel discussion said: "Decarbonising the power system requires generation technologies that are not just low carbon, but are also dependable and flexible. CCS stands head and shoulders above other technologies in providing all that is required to keep the lights on whilst providing a pathway to large scale industrial decarbonisation. Maintaining its profile through events like this is incredibly important in helping to focus attention on its remaining innovation priorities."

John Gale, General Manager at Greenhouse Gas R&D Programme said: "CCS is a critical technology that will allow the use of fossil fuels whilst still aiming to meet the Paris agreement target of below 2 degrees C. Reports such as this that draw attention and highlight the future role that CCS can play are important references for government, academia and industry stakeholders."

Guido Magneschi, Senior Advisor, The Global CCS Institute, who also took part in the panel, said: "This report is an excellent summary of future R&D challenges & opportunities in Carbon Capture and Storage."

Also in attendance was Rupert Wilmouth, Head of Energy, Government Office for Science, and Wilfreid Maas, General Manager CCS Technology, Shell.

Toshiba and MHIR to lead Japan's largest CCS project

www.mizuho-ir.co.jp

Toshiba and Mizuho Information & Research Institute (MHIR) will seek to contribute to the mitigation of climate change through the early deployment of CCS in Japan and overseas.

Toshiba, MHIR and 11 other entities have been selected to carry out a major five-year project to promote clean energy generation, the "Demonstration of Sustainable CCS Technology Project" sponsored by Japan's Ministry of the Environment (MOE).

The consortium led by the two companies will construct a large-scale carbon capture facility that will capture carbon dioxide (CO2) emitted by a thermal power plant, and evaluate the technology's performance, cost and environmental impacts. The project will run from 2016 to 2020, and the consortium will use the results to develop policies and measures to facilitate carbon capture and storage (CCS) deployment in Japan.

Toshiba will construct a carbon capture facility designed to capture more than 500 tons of CO2 a day, about 50% of its daily emissions, from the Mikawa Power Plant (capacity: 49,000 kW) operated by Toshiba subsidiary Sigma Power Ariake Co., Ltd., in Omuta, Fukuoka prefecture.

Mizuho and the other 11 members will investigate an environmental impact assessment method for CCS, the framework necessary for the smooth introduction of CCS in Japan, and overall CCS system appropriate to Japan. The demonstration project aims to achieve practical applications of this technology by 2020.

The Mikawa Power Plant is now being retrofitted to accommodate both coal- and biomass-fired power generation. When the demonstration facility is completed in 2020, it will become the world's first power plant*2 equipped with a large-scale carbon capture demonstration facility that is capable of capturing carbon dioxide from a biomass power plant.

Commenting on the project, Takao Konishi, Vice President of Toshiba's Energy Systems & Solutions Company said, "Toshiba is committed to the realization of a low-carbon society. Alongside CO2-free power generation methods, such as nuclear, renewables and hydrogen-based power, Toshiba is working on technologies for reducing CO2 emissions from thermal power plants, including CCS and ultra- supercritical coal-fired thermal power generation. Through this project in Mikawa, we aim to further increase the efficiency and scale of CCS as a step toward global promotion of cleaner energy production."

Yasushi Kaji, General Manager of MHIR said, "MHIR will work to improve the environment for deploying CCS as a measure against climate change as well as to formulate a national policy based on the findings of this project. MHIR will advance its efforts in the field of environment and energy in order to help realize a sustainable society by assisting with policy planning, corporate management, and R&D promotion."

The full consortium includes Chiyoda Corporation, JGC Corporation, Mitsubishi Materials Corporation, Taisei Corporation, Dia Consultants Co., Ltd., QJ Science Ltd., Japan NUS Co., Ltd., National Institute of Advanced Industrial Science and Technology (AIST), Central Research Institute of Electric Power Industry, The University of Tokyo, Kyushu University (The project leader is Dr. Makoto Akai, Emeritus Researcher at AIST/Board Director of Global CCS Institute.)

Imperial study shows renewables not sufficient to meet climate targets

www.teessidecollective.co.uk

A new paper from Imperial College London highlights the need for carbon capture and storage systems (CCS) in the age of renewables.

The paper has shown that carbon capture and storage technologies are essential, in addition to renewable energy systems, if the world is to meet current climate targets.

Policy-makers and industrialists from around the world are increasingly recognising the environmental and socio-economic issues around global climate change and the effects of carbon emissions of fossil fuel power plants on global warming, says the paper.

Experts generally agree that the route to a low-carbon energy system will involve the implementation of key technologies such as carbon capture and storage (CCS) systems applied to fossil fuel power plants or the use of renewable energy sources. Both of these solutions have numerous advantages and disadvantages; the former employs a non-renewable source that, through CCS technology, is made essentially decarbonised whereas the latter is dependent on fluctuating sources, making it unreliable as a sole power provider.

"In our current position where the use of fossil fuel energy is unavoidable, the case is undoubtedly not 'renewables or CCS' but rather 'renewables and CCS'," said Dr Niall Mac Dowell, Senior Lecturer in the Centre for Environmental Policy Engineering at imperail College and co-author.

The paper, titled "Quantifying the value of CCS for the future electricity system" shows that the combination of renewables and unabated fossil fuel power plants will not result in a sufficiently low carbon electricity system to meet current global climate targets.

They found that fossil fuel power plants will continue to be needed but that the utilisation of CCS systems is both necessary and inevitable. The researchers looked into production, demand and stability characteristics of current and future electricity systems. Instead of focusing on CCS costs, this study for the first time looked into the value provided to the electricity system by CCS power plants.

The authors compared electricity systems composed of unabated and abated (CCS) plants with wind power plants of differing wind availability to highlight the importance of differentiating between intermittent and firm power generators.

The paper shows that the preferred solution for decarbonising the electricity grid is a combination of renewable energy and CCS – it is not a case of one or the other, and when deployed in concert, the combination of CCS and renewable energy is key to the least cost decarbonisation of the electricity grid.

"Due to immense capital investments in fossil fuels, the energy sector continues to be slow to change with only 2.2% of the global energy consumption covered by renewable sources", said Dr Mac Dowell, "In our current position where the use of fossil fuel energy is unavoidable, the case is undoubtedly not 'renewables or CCS' but rather 'renewables and CCS'."

The complex cost-benefit analysis, published in Energy and Environmental Science was carried out by researchers from the Centre for Environmental Policy, the Centre for Process Systems Engineering and the Department of Chemical Engineering at Imperial College London.

They concluded that the trilemma between carbon avoidance, cost and security requires a delicate balance which cannot be made without considering every aspect of the electricity system simultaneously. Compromising on reliability cannot be an option given the high value of electricity in our society, which makes it necessary to combine intermittent and firm low-carbon supplies.

CO2 utilisation London policy conference

The UK think tank Policy Exchange ran a forum in London on June 6 looking at how to develop policy to encourage CO2 utilisation, with an opening talk from Lord Debden (John Gummer), chair of the UK government Committee on Climate Change.
By Karl Jeffery

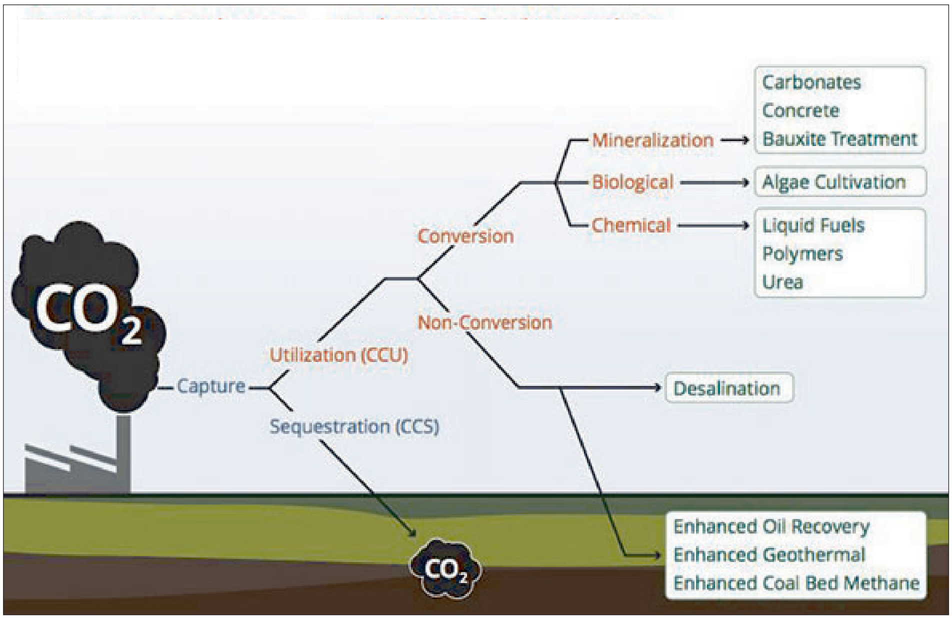
UK think tank Policy Exchange held a forum in London on June 6 called "rethinking CO2," looking at opportunities for CO2 re-use.

The opening speaker was Lord Debden, otherwise known as John Gummer, current chair of the government's Committee of Climate Change and a former Minister of Agriculture under Margaret Thatcher.

Lord Debden opened the conference trying to put CO2 utilisation in the context of what is happening in society at the moment.

"People find the science of climate change extremely difficult because people find science extremely difficult," he said.

"Sometimes when scientists complain about people not being very numerate, I want to say that there are an awful lot of scientists that aren't very literate. So trying to put over some of these issues is, I think, pretty difficult on both sides."



Paving the way – a selection of today's carbon capture and utilisation pathways

Range of elements

"I apologise if you feel that some of the points I make are obvious but clearly they haven't been obvious to members of the government, leave alone anyone else," he said.

"The first obvious fact is that if we are going to fight the battle of climate change then the answers are both/and, and not, either/or, that almost everything we talk about is going to have to be part of the answer."

"We as a committee are very clear in our minds that you have to have a range of elements if we are to have any chance of the sort of decarbonisation which we know is necessary."

"That doesn't mean to say that we want all of them at the same time nor does it mean that all of them we will have forever."

"When I have to make the argument about nuclear power it's perfectly possible to have a view which says that you need nuclear power as a transitional mechanism. It's perfectly possible to argue that you need gas, whether fracked or otherwise, as a transitional mechanism."

"What I think is pretty difficult to argue, is that there is one, simple answer to what is a very complex problem."

"And yet, there is a kind of enthusiasm that people have for their particular answer which very often excludes anybody else. I mean the number of people who are keen on wind energy who spend all the time they can being rude about solar and vice versa. [It] is a very annoying part of the whole debate."

"So I want to start by saying that there is a mix, and that in that mix there are certain, in my view, absolutely essential elements and one of them is that we decrease as fast as possible the heavily polluting means of generation."

"I applaud the government's decision to stop generation by coal earlier than we had expected, so there's that side of it."

"At the other side we have to recognise that we won't be able to handle the issues that we need without a number of elements, and carbon capture with or without storage is one of those elements. "

"The Climate Change Committee is very clear, we don't think that as we stand today that we can envisage a future in which we have got the emissions in Britain down to the 80 per cent cut to which we are statutorily required, leave alone moved beyond that, which is what Paris is now inviting us to do, unless we have carbon capture and storage."

"One of the problems of discussing this is that people confuse means and ends and they also confuse means of two different kinds.

I'm always interested in ends, my job as Chairman of the Climate Change Committee is to achieve certain ends. Frankly, if to achieve those ends it were possible to have the Secretary of State for Energy and Climate Change doing the splits every two seconds, I'd be in favour of it. I've got no hang ups about how you do it. What I'm interested in is reaching that end.

"Very many NGOs get themselves tied up with particular means. We have to be a bit careful about pretending that means and ends are the same thing."

"There is some room for arguing that without at least some element of particular means we're not going to achieve those ends. I think carbon capture and storage is very clearly one of those means."

Policy

Referring to the UK government's cancellation of a CCS competition in November 2015, he said, "we have to have an alternative route [to getting CCS in the UK] and the government really must provide an alternative route. The Climate Change Committee is absolutely clear about that."

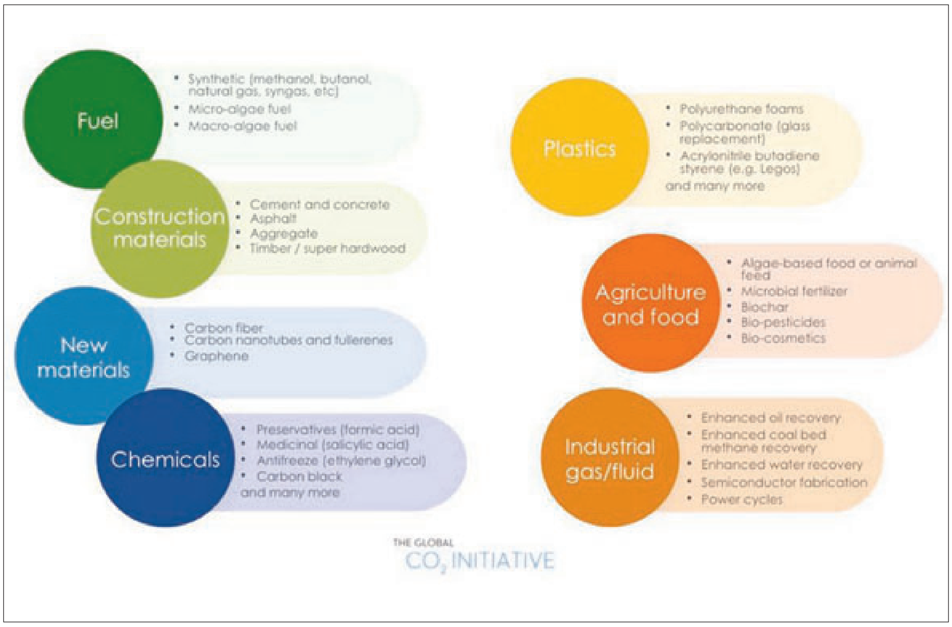
Whatever the reason for terminating the CCS competition, it was not helpful to industry confidence that the government did not immediately suggest a replacement scheme, but just said that it was 'committed to CCS', he said.

"As a strategic approach to reducing the cost of CCS, it is important to separate support for capture and support for transport and storage infrastructure, he said.

"I think we've suffered considerably by the mistaken conflation of those two elements."

It is important to be more focussed on the strategy, and the clusters we might need for the strategy, and to find a way to suitably allocate risk between public and private sectors, he said.

"I don't think we have in any way found the



There are many potential uses for compoumds derived from captured CO2

answer - which must be a mixed economy answer or it won't happen."

"Funding should be allocated competitively to minimise cost. A new instrument will be needed for industrial projects incorporating a similar competitive element. "

"We also need to recognise that you need a sufficient scaled, targeted rollout, you can't do this without a combination of industry and power plants necessary to realise the economies of scale and to allow the build-up of skills, developer and financial interest."

"Our pressure on the government will be to recognise that we in Britain really do need to start on this route."

"It's important for us because we cannot reach the target we need in decarbonisation without enormous extra cost if we don't have it. It's important for us because we ought to be the innovative leaders of this matter. "

"We ought to be the leaders inside the European Union because we don't have the hang ups over CCS which some countries do have. "

The major barrier is the uncertainty, and this is something the Climate Change Committee is seeking to "get the government to overcome," he said.

"It doesn't matter whether you're free marketers or not, government has a role to play in the establishment of priorities and in the delivery of certainties in what is a very uncertain world. Until there is a real sense in this country that the government is serious about the whole project, it's difficult to get quite a lot of people on board."

CO2 re-use

Coming onto CO2 re-use, he said, "it would be made all the easier if we could see CO2 not as a waste but as a resource."

"I think it can be taken for granted that we need CCS, it can be granted therefore that we need CC, it can be taken for granted that CCS will be a darn sight easier if the CC actually led you to something that was worth storing or using."

"It's going to be a very hard and, I think, longer than I would like, road, but that doesn't mean to say that it won't be quicker if we start now."

More information

A full video, transcript and slides for the event is online at:

policyexchange.org.uk

CO2 utilisation and kinetics

To understand how CO2 utilisation can work, you need to understand the reaction kinetics – energy and catalysts, said Peter Styring from the University of Sheffield.
By Karl Jeffery

Many people say CO2 utilisation can't work easily because CO2 is unreactive, said Professor Peter Styring, director of research in chemical and biological engineering with the University of Sheffield.

The word 'unreactive' is probably referring to the thermodynamics, it usually takes an input of energy to make CO2 react. But another issue is the kinetics, how you get the reaction moving, with energy and a catalyst. You need to think about thermodynamics and kinetics together, he said.

For the environmental argument to make sense, "that energy must come from perennial or renewable sources of heat, it cannot come from fossil fuels," he said.

Urea and salicylic acid production are well established carbon utilisation technologies, in some cases for over a century, he said.

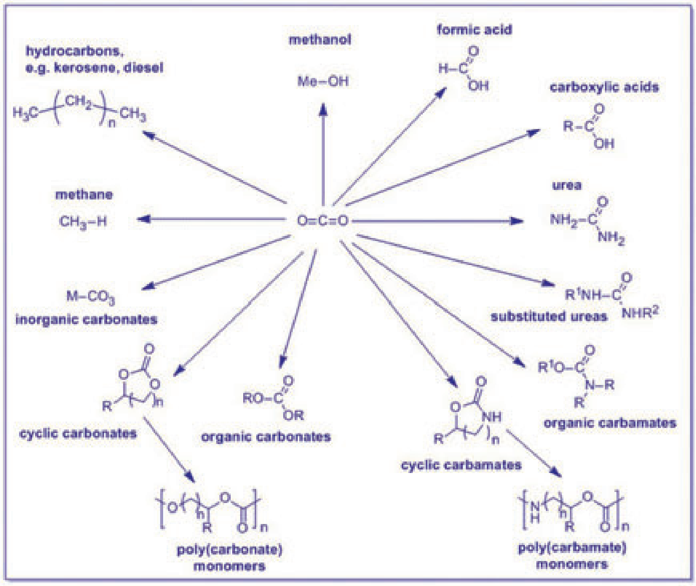
Professor Styring is involved with CO2Chem, the Carbon Dioxide Utilisation Network, supported by the EPSRC (Engineering and Physical Sciences Research Council) Grand Challenge Network, which advocates CCU across the world. It has a £4.7m grant for research, involving four universities over 4.5 years. Meanwhile the German government has invested around Eur 400m in carbon dioxide utilisation, he said.

Professor Styring is also involved in the European Commission funded "Scot Project". "It's seeking to reform the ETS to include carbon capture and utilisation, particularly accelerated mineralisation," he said.

The Scot Project focussed on transport fuels, accelerated mineralisation of the built environment, and for chemical feedstocks for the sustainable chemicals industry. The project formally ends in 2016 but the work will be continued in a 2 year project called Carbon Net.

"So through CCU we have the opportunity to redefine the chemicals industry," he said. "We hope to be able to make a more sustainable supply chain and, at the same time, reduce net CO2 emissions."

"Academia, industry and government will have the opportunity to make the UK the world leading nation in CCU. North America was mentioned but Germany is by far the strongest at the moment. By making the UK the world leaders in CCU that should also have a knock-on effect that we'll become world leaders in CCS because the CC is common to both. "



Some chemical pathways for converting CO2 to other compounds

Lifecycle analysis and EOR

One issue is the complexity in whether the CO2 ultimate ends. If CO2 is captured and used as a vehicle fuel, then it ends up in the atmosphere, although probably displaces fossil vehicle fuel. CO2 used for EOR will lead to more fossil fuel production. This can all make challenges for policy makers.

"We need lifecycle assessment over the processes, but they need to be clear, they need to be honest," said Professor Peter Styring.

But on the other side of the argument, it is proving very hard to get CCS projects financed and EOR helps. There are 2.1 megatons of CO2 being captured for non EOR projects, and 27 megatons including EOR projects, he said.

Also consider Norway, which has planned to take petroleum based cars off its roads by 2025, but will still be producing oil and gas.

Purity

If the CO2 is supplied in a less pure form, for example 50 per cent CO2, the cost of generating CO2 can be much lower, Professor Styring said.

Sometimes too much oxygen mixed with CO2 is an issue in CO2 utilisation projects, sometimes it isn't, he said. NOx and SOx can be tolerated, depending on what catalysts are use.

We need to match the technology to the industry, but by using a modular system for capture, we can go at whatever purity we like. It's not aiming to give you 99% purity.

More information

co2chem.co.uk
www.sheffield.ac.uk/cbe

Carbon8 – reacting CO2 with waste to make aggregates

UK company Carbon8 is reacting CO2 with different types of waste to make building materials. By Karl Jeffery

Professor Colin Hills, University of Greenwich and Founder Director of Carbon8 Systems, presented his company's technology which reacts waste with CO2, at the Policy Exchange event.

The technology is not going to save the planet by itself, but is presented as a benchmark, "something that is out there, it's working in a commercial environment and it's producing a product that's fit for purpose," he said.

The technology copies what the earth has done over billion of years, mineralising CO2 in the atmosphere, he said. "In research that's going back more than a decade, we've found that we can y react a whole range of different, high-volume industrial waste streams with CO2 and that carbon dioxide is mineralised as carbonates, such as the chalk."

"If we managed the reaction environment, we can actually produce a solid, and that solid has the sort of properties that enable reuse."

Carbon8 aggregate plant in Avonmouth

The company has experimented with a variety of waste, including bauxite, red mud, paper ashes, metal dust, to make an aggregate (building material).

"We can mimic earth processes in a controlled environment to make an aggregate in thin section, in about 15 minutes. Not your hundreds of millions of years."

By adjusting system parameters such as moisture, rotation, speed, resonance time and batch size, you can get a range of different particle sizes and shapes, so materials which can be used in different purposes, he said.

The UK uses about 250m tones a year of aggregate, and the world uses about 25 gigatonnes, he said. Meanwhile there is probably about 1 gigatonnes of waste which can be reacted with CO2 produced every year around the world, he said. This waste could be reacted with big CO2 sources to make building materials.

The produce needs to be cheap, fit for purpose, and fit with regulatory standards, he said.

Carbon8 has UK government agreement to sell its aggregates to the building industry, to be incorporated in concrete blocks. They meet European standards for lightweight aggregate, and medium-dense aggregate. It is possible to make sheet materials.

Currently, Carbon8 uses CO2 supplied by tanker, which is expensive. "We'd rather have it out of the end of pipe from a flue gas somewhere."

Carbon8 currently produces aggregate at about 150,000 tons per year, with plans to increase to half a million by 2020, he said. "Now that may sound like a lot to you, but if you consider that a medium-sized block manufacturer would be making a million tons of blocks a month".

"You do not need food grade CO2 for making building aggregates," he said. "An air stream containing just 50 per cent CO2 will work. Although "if it was laced with sulphurous gasses there needs to be an element of scrubbing."

To make it work, lower cost methods of CO2 capture would really help, he said.

One obstacle of conservative thinking. One construction company said "We won't use any new materials unless they've been around and used for 10-15 years," he said.

Although you can argue that the company's aggregates are made the same way as rock (from the earth), just over a timescale of minutes rather than millions of years, he said.

"There has to be some acceptance there that they will be fit for purpose but they're not necessarily like for like."

More information

www.c8s.co.uk

CCSA – many members interested in CO2 re-use

Many members of the Carbon Capture and Storage Association are interested in finding commercial applications for CO2, said chief executive Luke Warren.,

Luke Warren, Chief Executive of the Carbon Capture and Storage Association (CCSA), said that many of the companies in his membership are interested in CO2 re-use.

"These are commercial enterprises, and very efficient at finding opportunities to either sell or give away their CO2, rather than have to pay to store it," he said.

One CCSA member is capturing CO2 from a refinery and piping it to a greenhouse, where it displaces paraffin which would otherwise be burnt to elevate CO2 levels, leading to a net CO2 saving.

The most obvious example of CO2 utilisation is its use in enhanced oil recovery, which has been going on for 40 years in North America, currently storing "tens of millions of tons" of CO2 per year.

"Certainly there is a lot of interest in trying to replicate those CCU markets in other regions around the world."

"I think the term CCU probably really started in North America, which I think is a reflection of the mature CCU market there," he said.

"Here in the UK, one of the obvious large-scale CCU opportunities is the potential to use CO2 in the North Sea, particularly in the Central North Sea, to improve production of depleting oil fields there.

"The biggest limit on the growth of CO2 EOR technologies is access to CO2, and certainly the view of many operators in the North Sea is that CO2 EOR will never really take off until we actually have CCS starting to be developed at scale."

Once there is CO2 being brought to the North Sea, oil and gas companies "will undertake the pilot studies and they will look to see if there are commercial opportunities to deploy that technology," he said.

It might be helpful for government to look at how these different sectors could be brought together to identify synergies, he said.

"One of the tragedies from our perspective is the decision at the spending review back in November 2015, to cancel the two CCS competition projects," he said. "That removed the potential to get the CO2 into the central North Sea."

"There were certainly I think a number of operators looking at how they might be able to utilise those volumes to undertake some pilot injections and then use that to then undertake a full-scale injection in the 2020s."

Meanwhile, in many industrial areas like Teesside, food grade CO2 is being vented to the atmosphere. It comes from industrial processes where CO2 is captured as part of the process, he said. "Obviously if they can develop a revenue stream for that CO2 they will do so. They sell as much of it as they can into the market, so you see a lot going into the food and beverage market. But there's only so much CO2 that you can actually supply to these markets."

"The rest of it is simply vented to atmosphere. There's no other process by which they can abate those CO2 emissions. There are no markets at the moment that can address the volumes of CO2 that's produced by UK industrial activity."

Scale mismatch

One challenge is that there is scale-mismatch between carbon capture and CO2 utilisation. "The companies that we mainly interact with, are large emitters, energy-intensive industries, and the power sector. They don't yet see that CCU technologies are applicable at the scale that's relevant to them," Mr Warren said.

"They are looking at how they can transition to a low-carbon economy over the next decade, 15 years or so, and at the moment those opportunities don't seem to be there from CCU. So it seems that for many of these sectors actually CCS is the only technology that's available."

Luke Warren, Chief Executive of the Carbon Capture and Storage Association

The UK government recently funded research into how much CO2 could be used by British business, and estimated 0.5 to 0.7m tons a year under a 'moderate' scenario, and 3-4m under a 'high' scenario.

"It's not going to deliver the emission reductions at the scale that is implied by the various carbon budgets that have been established," he said.

Globally, "by the middle of the century you could be looking at perhaps a market size [for CO2 re-use] of 600 million tons of CO2 a year, but this is in the context of a world that today is emitting 32 gigatonnes of CO2 a year."

Professor Peter Styring agreed that at the moment CCU technologies are often at a laboratory table scale, research work was needed to get them to a higher 'technology readiness level' and a bigger scale, because it is only that way that they can become cost competitive.

More information

www.ccsassociation.org

Getting CO2 re-use moving

There was a discussion session at the CO2 re-use forum about the best way to get a CO2 re-use industry moving – what kind of public relations, policy, carbon prices, retrofitting practise, government grant and energy system schemes would work

"All of these very clever carbon capture and utilisation ideas and projects require political infrastructure, they require communication with a public that doesn't understand," said Nigel Vibart Dixon, CEO of Freedom, a renewables consultancy, as a question to the speakers.

"My challenge to the Committee for Climate Change, is to up your game on PR [public relations]." "You've got to grab some sexy headlines, you've got to shake up public opinion, because the government will only react to public opinion."

Lord Debden replied, "I've been in politics in one way or another for a very, very long time, and when things aren't going as you'd like them to do, the answer is always you've really got to get the PR better, you've actually got to get out there and get people to understand it."

"The Climate Change Committee is neither constituted nor placed to do the PR. We neither have the resources nor indeed is that what our job is. Our job is to provide the means whereby people can do that job. We provide the information, we provide the scientific backup, and we provide the judgement. We will proceed, in the very near future, to lay out what we think to be the parameters and priorities for the government in terms of CCS. "

"Before the end of the month [June 2016] comes our document on assessment of the last year; then there will be some further extension on the CCS matter, and then the government will have a further document which will say what issues we think it's got to cover in its own statement about how it's going to meet the fourth and fifth carbon budget."

"In the meantime the government will have made its announcement about the fifth carbon budget."

"I, frankly, would be delighted to be in the PR business on this front, but we aren't, we can't be, neither statutorily can we be."

"I need to have the scientific base to be able to make any statement at all which is where I spend my money. I spend it on being able to tell people what is true."

Professor Styring said "it's people like us, or the Scot Project, who do advocacy work."

For example, "we're organising the international conference in Sheffield in September, the biggest conference on carbon dioxide utilisation, and for the first time it's coming to the UK. On the final day, the Thursday, we have politicians, industry coming in from Europe, where we're going to look at the political context, we're going to look at the public perception," he said.

CCSA's Luke Warren said that the European Commission deserves more credit for its efforts trying to promote CCS in Europe. "Their state aid guidelines are very, very clear, that they will take a very favourable view of state aid for CCS," he said.

"In fact I think they're quite concerned that Europe has not developed a technology and other regions [in the world] have actually really started to progress quite far with the technology. If that's not addressed in the near term, then potentially Europe starts to present itself with a structural challenge in terms of how it's going to decarbonise, particularly as we move forward into the 2030s and beyond."

"It's actually been the member states that haven't come forward with the complementary national policies that probably held back CCS in Europe."

Costs and carbon prices

High carbon prices could make a big difference, Lord Debden said. "This world doesn't work unless people start paying the proper price for things. The proper price is the cost to individuals and the community of doing particular things."

However "the immediate importance is lowering the price of being able to capture. Unless you can lower that price of capture, you're not going to be in a position either to use it or indeed to store it.

"Don't forget that most of the cost reductions in offshore wind have come from things which are really nothing to do with offshore wind," he said. They come "because there has been a demand, because there is a long order book ahead, you've been able to build them onshore, use bigger boats, therefore put these things up for ten months of the year and not five months of the year."

"You've been able to do all sorts of terribly ordinary things, which have slashed the price."

"And if you look at the actual technological, I mean not in the technical sense but in the way the public would think of it, there has been very little change in this. It's not just technical innovation, it is mechanistic innovation."

Cornell scientists convert carbon dioxide, create electricity

Cornell scientists have designed a CO2 capture technology that produces electricity.

Lynden Archer, the James A. Friend Family Distinguished Professor of Engineering, and doctoral student Wajdi Al Sadat have developed an oxygen-assisted aluminum/carbon dioxide power cell that uses electrochemical reactions to both sequester the carbon dioxide and produce electricity.

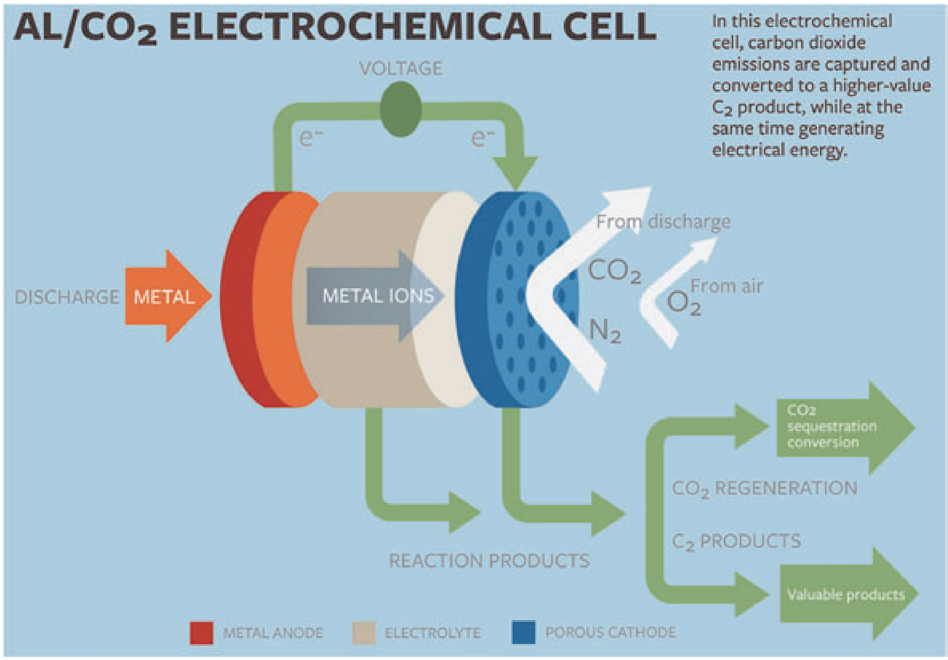
Their paper, "The O2-assisted Al/CO2 electrochemical cell: A system for CO2capture/conversion and electric power generation," was published July 20 in Science Advances.

The group's proposed cell would use aluminum as the anode and mixed streams of carbon dioxide and oxygen as the active ingredients of the cathode. The electrochemical reactions between the anode and the cathode would sequester the carbon dioxide into carbon-rich compounds while also producing electricity and a valuable oxalate as a byproduct.

In most current carbon-capture models, the carbon is captured in fluids or solids, which are then heated or depressurized to release the carbon dioxide. The concentrated gas must then be compressed and transported to industries able to reuse it, or sequestered underground. The findings in the study represent a possible paradigm shift, Archer said.

"The fact that we've designed a carbon capture technology that also generates electricity is, in and of itself, important," he said. "One of the roadblocks to adopting current carbon dioxide capture technology in electric power plants is that the regeneration of the fluids used for capturing carbon dioxide utilize as much as 25 percent of the energy output of the plant. This seriously limits commercial viability of such technology. Additionally, the captured carbon dioxide must be transported to sites where it can be sequestered or reused, which requires new infrastructure."

The group reported that their electrochemical cell generated 13 ampere hours per gram of porous carbon (as the cathode) at a discharge potential of around 1.4 volts. The energy produced by the cell is comparable to that produced by the highest energy-density battery systems.



Another key aspect of their findings, Archer says, is in the generation of superoxide intermediates, which are formed when the dioxide is reduced at the cathode. The superoxide reacts with the normally inert carbon dioxide, forming a carbon-carbon oxalate that is widely used in many industries, including pharmaceutical, fiber and metal smelting.

"A process able to convert carbon dioxide into a more reactive molecule such as an oxalate that contains two carbons opens up a cascade of reaction processes that can be used to synthesize a variety of products," Archer said, noting that the configuration of the electrochemical cell will be dependent on the product one chooses to make from the oxalate.

Al Sadat, who worked on onboard carbon capture vehicles at Saudi Aramco, said this technology in not limited to power-plant applications. "It fits really well with onboard capture in vehicles," he said, "especially if you think of an internal combustion engine and an auxiliary system that relies on electrical power."

He said aluminum is the perfect anode for this cell, as it is plentiful, safer than other high-energy density metals and lower in cost than other potential materials (lithium, sodium) while having comparable energy density to lithium.

He added that many aluminum plants are already incorporating some sort of power-generation facility into their operations, so this technology could assist in both power generation and reducing carbon emissions.

A current drawback of this technology is that the electrolyte – the liquid connecting the anode to the cathode – is extremely sensitive to water. Ongoing work is addressing the performance of electrochemical systems and the use of electrolytes that are less water-sensitive.

This work made use of the Cornell Center for Materials Research, which is supported by the National Science Foundation. Funding came from a grant from the King Abdullah University of Science and Technology Global Research Partnership program.

More information

www.ccmr.cornell.edu

Solar cell captures CO2 and produces fuel

Researchers at the University of Illinois have engineered solar cell that cheaply and efficiently converts atmospheric carbon dioxide directly into usable hydrocarbon fuel, using only sunlight for energy.

The finding is reported in the July 29 issue of Science and was funded by the National Science Foundation and the U.S. Department of Energy. A provisional patent application has been filed.

Unlike conventional solar cells, which convert sunlight into electricity that must be stored in heavy batteries, the new device essentially does the work of plants, converting atmospheric carbon dioxide into fuel, solving two crucial problems at once. A solar farm of such "artificial leaves" could remove significant amounts of carbon from the atmosphere and produce energy-dense fuel efficiently.

"The new solar cell is not photovoltaic — it's photosynthetic," says Amin Salehi-Khojin, assistant professor of mechanical and industrial engineering at UIC and senior author on the study.

"Instead of producing energy in an unsustainable one-way route from fossil fuels to greenhouse gas, we can now reverse the process and recycle atmospheric carbon into fuel using sunlight," he said.

While plants produce fuel in the form of sugar, the artificial leaf delivers syngas, or synthesis gas, a mixture of hydrogen gas and carbon monoxide. Syngas can be burned directly, or converted into diesel or other hydrocarbon fuels.

The ability to turn CO2 into fuel at a cost comparable to a gallon of gasoline would render fossil fuels obsolete.

Chemical reactions that convert CO2 into burnable forms of carbon are called reduction reactions, the opposite of oxidation or combustion. Engineers have been exploring different catalysts to drive CO2 reduction, but so far such reactions have been inefficient and rely on expensive precious metals such as silver, Salehi-Khojin said.

"What we needed was a new family of chemicals with extraordinary properties," he said.

Amin Salehi-Khojin & Mohammad Asadi

Amin Salehi-Khojin (left), UIC assistant professor of mechanical and industrial engineering, and postdoctoral researcher Mohammad Asadi with their breakthrough solar cell that converts atmospheric carbon dioxide directly into syngas.

Salehi-Khojin and his coworkers focused on a family of nano-structured compounds called transition metal dichalcogenides — or TMDCs — as catalysts, pairing them with an unconventional ionic liquid as the electrolyte inside a two-compartment, three-electrode electrochemical cell.

The best of several catalysts they studied turned out to be nanoflake tungsten diselenide.

"The new catalyst is more active; more able to break carbon dioxide's chemical bonds," said UIC postdoctoral researcher Mohammad Asadi, first author on the Science paper.

In fact, he said, the new catalyst is 1,000 times faster than noble-metal catalysts — and about 20 times cheaper.

Other researchers have used TMDC catalysts to produce hydrogen by other means, but not by reduction of CO2. The catalyst couldn't survive the reaction.

"The active sites of the catalyst get poisoned and oxidized," Salehi-Khojin said. The breakthrough, he said, was to use an ionic fluid called ethyl-methyl-imidazolium tetrafluoroborate, mixed 50-50 with water.

"The combination of water and the ionic liquid makes a co-catalyst that preserves the catalyst's active sites under the harsh reduction reaction conditions," Salehi-Khojin said.

The UIC artificial leaf consists of two silicon triple-junction photovoltaic cells of 18 square centimeters to harvest light; the tungsten diselenide and ionic liquid co-catalyst system on the cathode side; and cobalt oxide in potassium phosphate electrolyte on the anode side.

When light of 100 watts per square meter – about the average intensity reaching the Earth's surface – energizes the cell, hydrogen and carbon monoxide gas bubble up from the cathode, while free oxygen and hydrogen ions are produced at the anode.

"The hydrogen ions diffuse through a membrane to the cathode side, to participate in the carbon dioxide reduction reaction," said Asadi.

The technology should be adaptable not only to large-scale use, like solar farms, but also to small-scale applications, Salehi-Khojin said. In the future, he said, it may prove useful on Mars, whose atmosphere is mostly carbon dioxide, if the planet is also found to have water.

"This work has benefitted from the significant history of NSF support for basic research that feeds directly into valuable technologies and engineering achievements," said NSF program director Robert McCabe.

"The results nicely meld experimental and computational studies to obtain new insight into the unique electronic properties of transition metal dichalcogenides," McCabe said.

"The research team has combined this mechanistic insight with some clever electrochemical engineering to make significant progress in one of the grand-challenge areas of catalysis as related to energy conversion and the environment."

More information

"Nanostructured transition metal dichalcogenide electrocatalysts for CO2 reduction in ionic liquid" is online at:

www.eurekalert.org/jrnls/sci

www.uic.edu

Capture and utilisation news

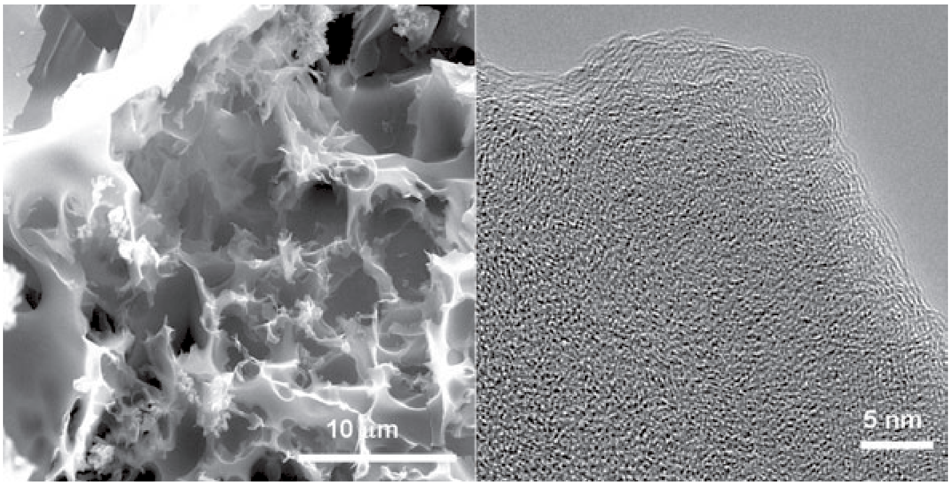
Study of carbon capture materials maximises effectiveness

barron.rice.edu

A careful balance of the ingredients in carbon-capture materials would maximize the sequestration of greenhouse gases while simplifying the processing of natural gas, according to researchers at Rice University.

The lab of Rice chemist Andrew Barron led a project to map how changes in porous carbon materials and the conditions in which they're synthesized affect carbon capture. They discovered aspects that could save money for industry while improving its products.

The research appears in the Royal Society of Chemistry's Journal of Materials Chemistry A.



High-resolution transmission microscope (left) and scanning electron microscope images of a porous carbon sample studied for its ability to capture carbon dioxide from natural gas. (Image: Barron Research Group/Rice University)

The lab compared how characteristics of porous carbon, often manufactured in pellet form, affect carbon dioxidecapture. Temperature, pressure, the material's surface area, the size of its pores and what elements are added all impact results, Barron said. He said the map will influence how carbon capture research is carried out from now on.

"The traditional sense has been the more surface area and the greater the porosity of the material, the better it will adsorb," Barron said. "So people have been synthesizing materials to maximize both. It turns out that's kind of a dead area of research because once you get to a critical number, no matter how high you get after that, they don't improve absorption.

"What we've done is provide a recipe to make carbon capture materials the best they can be," he said.

The researchers made a variety of porous carbon materials from sources like pulverized coconut shells and sawdust and treated them with potassium hydroxide to give the grains nanoscale pores. Some batches were enhanced with nitrogen and some with sulfur; these have been studied as additives to make materials more adsorbent.

The researchers used a variety of precursors to synthesize porous carbon-based sorbent materials chemically activated at temperatures between 500 and 800 degrees Celsius (932 to 1472 degrees Fahrenheit) and carefully measured their carbon dioxide-capturing capacities at pressures between 0 and 30 bar. (One bar is slightly less than the average atmospheric pressure at sea level.)

Regardless of the functional additives, experiments showed that once a sorbent material achieved a surface area of 2,800 square meters per gram and a pore volume of 1.35 cubic centimeters per gram, neither more surface area nor larger pores made it more efficient at capturing carbon dioxide.

"Trying to make something with a higher pore volume doesn't help," Barron said. "Higher surface area doesn't help. Once you get to a certain point, no matter what you do, you're not going to get any better with a certain material."

The researchers also discovered the best conditions for carbon capture aren't the same as those that achieve the best trade-off between carbon and methane selectivity. An ideal material would capture all the carbon dioxide and let all the energy-containing methane pass through, Barron said.

"The barrier where it doesn't help you any more is different for the total uptake of carbon dioxide than it is for the selectivity between carbon dioxide and methane," he said. "Industry doesn't have to be making the highest-surface-area material. They just have to make it with a surface area that reaches maximum production."

They determined a material with less than 90 percent carbon and enhanced by oxygen, rather than nitrogen or sulfur, worked best for both carbon capture and methane selectivity, especially for materials activated at temperatures approaching 800 degrees Celsius. Materials with a surface area above 2,800 square meters per gram excelled at absorbing carbon dioxide at pressures of 30 bar, but the advantages of such high surface area diminished at lower pressures.

The presence of oxygen, added by the pore-inducing potassium hydroxide, was far more relevant to the results than either nitrogen or sulfur, they found.

"We understand oxygen is important," Barron said. "We don't understand why. Does it stabilize certain pore structures? Is it because it stabilizes the pore neck? Is it changing the shape of pores? We don't know whether it's a chemical or physical issue, but now we know what we should study next."

BASF and Linde pilot project completes

www.basf.com

www.linde.com

BASF and Linde have successfully completed a joint pilot project to improve capture of carbon dioxide from flue gas at a coal fired power plant at the National Carbon Capture Center (NCCC) in Alabama.

The pilot plant captured up to 30 tons of CO2 per day at more than 90 percent capture rate and at a CO_2 purity of more than 99.9 percent.

The NCCC is a U.S. Department of Energy (DOE) research facility managed and operated by Southern Company, in Wilsonville, Alabama. Since January 2015, the project operated a pilot plant under a cooperative agreement with DOE's National Energy Technology Laboratory (NETL). Based on the successful completion, BASF and Linde will begin larger-scale testing and explore commercial opportunities.

The technology used during the pilot project integrates BASF's advanced aqueous amine-based solvent and process technology, marketed by BASF under the OASE® blue brand, with novel CO_2-capture process and engineering innovations developed by Linde. Parametric and long-duration testing confirm the main performance targets set for the facility. Specifically, it captured more than 90 percent CO_2 from the flue gas while the purity of the CO_2 was more than 99.9 percent.

The design capacity of the operation was up to 1.5 Megawatt-electric (MWe) and required less than 2.8 gigajoules of regeneration steam per metric ton of CO_2. The NCCC includes a post-combustion carbon capture facility that allows testing and integration of advanced technologies using actual coal-derived flue gas from an 880-MW pulverized coal unit at Alabama Power's Plant in Gaston. The pilot plant has operated at the facility for more than 1,200 hours at a higher regeneration pressure of 3.4 bar absolute, thereby demonstrating a cost advantage over other amine-based technologies.

"The amine-based OASE blue technology offers significant benefits for CO_2 capture as it aims to reduce the regeneration energy requirements using novel solvents," said Dr. Andreas Northemann, Vice President of BASF's OASE Gas Treating Excellence. "Long-term pilot testing demonstrated the solvents' performance and stability. BASF's almost 50 years of experience in industrial gas treating, combined with the expertise of Linde in large-scale engineering, procurement and construction, will lead us to the commercial scale-up of OASE blue technology."

The pilot plant at the National Carbon Capture Center followed on the earlier experience that Linde and BASF jointly gained in a similar project in Germany. Together with BASF and Germany's power plant operator RWE, Linde installed a pilot plant for carbon capture in Niederaussem, Germany in 2009.

Government of Canada announces support for Inventys

www.inventysinc.com

www.nrc-cnrc.gc.ca

Inventys is receiving up to $275,000 from the Government of Canada to deliver its VeloxoTherm CO_2 capture technology.

The funding will go toward the development of Inventys' next generation VeloxoTherm system, a solid adsorbent technology. The VeloxoTherm system is a low-cost, non-toxic technology that captures CO_2 from post-combustion emissions and is used by the energy and industrial sectors for greenhouse gas reduction.

The investment is made through the National Research Council of Canada Industrial Research Assistance Program (NRC-IRAP), which supports thousands of small and medium-sized enterprises in Canada every year in developing and commercializing innovative technologies.

"Inventys has the potential to develop a Canadian-made, new-to-the-world adsorption technology for carbon capture that removes the barriers to a low-carbon economy," said Inventys' Executive Chairman, Wayne G. Thomson. "Funding from NRC-IRAP and the program's hands-on approach continues to have a significant impact on the development of our transformative clean energy technology."

NRC-IRAP has worked with Inventys since 2008, attracting other investors and influencing the company's growth from two to 22 employees.

ION Engineering signs test agreement with TCM

www.ion-engineering.com

The project at Mongstad aims To further scale-up and validate ION's proprietary CO_2 capture technology

This next step in the development of ION's liquid absorbent system is the continuation of a multi-year Cooperative Funding Agreement with the U.S. Department of Energy's National Energy Technology Laboratory (NETL). In total, ION will receive over $16 million in funding from NETL. Previously, ION successfully completed testing of its technology at the National Carbon Capture Center (NCCC) at the pilot scale in 2015.

The collaborative project between TCM, ION, and NETL, will demonstrate ION's liquid absorbent system at TCM's existing 12 MWe test facility that utilizes industrial flue gases to simulate coal-fired conditions. Starting in October this year, this test program aims to further validate ION's leading capture technology and its readiness for commercial scale deployment.

Alfred "Buz" Brown, ION's CEO said, "Technology Center Mongstad is an ideal environment that allows us to validate our process at a large industrial test facility. The opportunity to test at TCM represents the final step in our ability to deploy our technology at commercial scale."

CO_2 Solutions sells commercial CO_2 capture unit

www.co2solutions.com

The project is to be realized in Quebec with Resolute Forest Products and Serres Toundra at a pulp mill.

The company has signed a commercial agreemen for the deployment of a carbon capture unit at a pulp mill in the Saint-Félicien region of Quebec and the commercial reuse of the CO_2 in an adjacent greenhouse.

The project, budgeted at $7.4 million, involves the capture of up to 30 tonnes-CO_2/day (tpd) from Resolute's softwood kraft pulp mill in Saint-Félicien and its transportation to Serres Toundra's neighbouring world-class vegetable greenhouse. By improving the performance of the greenhouse, while at the same time reducing the carbon emissions of the pulp mill, the reuse of the captured CO_2 will provide tangible benefits to both Resolute and Serres Toundra.

The project is specifically designed to minimize the footprint and capital cost of the carbon capture unit. The innovative design of the equipment further reduces the already low cost of CO_2 Solutions' technology and will be applicable in subsequent projects. Following a six-month demonstration period, Serres Toundra has agreed to purchase the captured CO_2 for a period of ten years thereafter. Based on the terms of the Agreement, CO_2 Solutions expects to realize revenues of approximately $400,000 annually from the sale of captured CO_2 and associated carbon credits.

Transport and storage news

Study of CO2 flow through North Sea geology will help select storage sites

www.strath.ac.uk

Scientists at the University of Strathclyde have secured funding for a four-year project to study the ability of complex rock strata beneath the North Sea to trap CO2 securely.

Their findings will help to provide the tools for selecting the most suitable CO2 storage sites as part of the large-scale development of carbon capture and storage, a key climate change technology. These tools could also greatly expand the potential for CO2 storage worldwide.

The study will look at how CO2, when injected into rocks deep below ground, could migrate upwards through the overlying strata, or overburden. The greenhouse gas can become trapped by dissolving into water-filled spaces between the rock grains. In more complex geology, where the fluids flow through complex pathways, there may be more potential for trapping CO2 as it rises, thereby minimising the risk of it escaping to the surface.

However, fault zones cutting geological layers could potentially provide shortcuts past the layers where CO2 could be trapped. The project team will investigate how the faults and rock strata interact to change the pathways for CO2 flow through the overburden.

The researchers from Strathclyde, an SCCS partner institute, will work with fellow scientists from the Universities of Cambridge and Imperial, and the British Geological Survey as part of a larger research project funded by Natural Environment Research Council (NERC).

Professor Zoe Shipton, University of Strathclyde, who will lead the fault zone study, said: “The rock types found within fault zones will change depending on the rocks that they cut. By understanding how the fault rock types influence mechanisms such as capillary trapping, dissolution of CO2 in water and migration pathways, our work can guide strategies for quantifying and reducing the risks of CO2 leakage from geological storage sites.

“We will construct simplified models of flow along layered strata with cross-cutting faults, alongside our partners’ laboratory analogue experiments, in order to constrain the effect of geological complexity on the fate of CO2 leaking from a subsurface storage site.”

The researchers will also look at real-life examples of CO2 storage – for example, Norway’s Sleipner project in the North Sea – to test their findings. The UK is geologically well placed to implement offshore CO2 storage, with many potential reservoirs in the geology beneath the UK’s North Sea.

Water sampling technique to monitor underground CO2 storage

A simple, cost-effective way to monitor CO2 stored underground has been developed by a UK-Australian collaboration.

In the first experiment of its kind, researchers studied the different forms of oxygen in waters sampled from rocks deep below ground at the storage site in the Otway Basin, in south eastern Australia.

They found that the reservoir's waters changed their oxygen composition when in contact with bubbles of trapped CO2. Testing samples of water for this altered form of oxygen provides a simple way to measure the amount of CO2 stored within the rock.

The study shows that injected CO2 is very quickly retained in the underground rocks, with CO2 being locked away like air being trapped within a foam sponge. The research was carried out by the Universities of Edinburgh and Australian research organisation CO2CRC.

Researchers say their technique provides an inexpensive monitoring solution, as they need only measure only CO2 injected into a site and water samples from before and after injection to find out how much CO2 is trapped.

The study, published in the International Journal of Greenhouse Gas Control, was supported by the UK Carbon Capture and Storage Research Centre and CO2CRC.

Dr Sascha Serno, of the University of Edinburgh's School of GeoSciences, who led the study, said: "Our results highlight the promising potential of using oxygen compositions to monitor the fate of CO2 injected underground. This method is simple and cheap, and can be easily combined with other monitoring techniques for CCS projects in the UK and beyond."

Dr Stuart Gilfillan, also of the School of GeoSciences, the study co-ordinator, said: "Understanding the fate of CO2 injected into the underground for storage is essential for engineering secure CO2 stores. Our work with our Australian partners paves the way for better understanding of the fate of CO2 when we inject it underground."

More information

www.co2crc.com.au
www.ed.ac.uk/geosciences

Scotland's industry 'clusters' hold key to reducing cost of UK climate action

A report from Scottish Carbon Capture & Storage (SCCS) advises the UK Government to focus on shared infrastructure to reduce carbon capture and storage cost.

A new study of "clusters" of industrial facilities in Scotland supports recent advice to the UK Government that a focus on delivering shared transport and storage infrastructure can greatly reduce the cost of achieving deep cuts in the UK's carbon emissions.

The analysis published by Scottish Carbon Capture & Storage (SCCS) shows how re-using existing natural gas pipelines, which pass close to centres of industrial activity, can reduce the cost of transporting captured carbon dioxide (CO2) to geological storage sites already identified offshore.

The UK's Committee on Climate Change (CCC) recently set out a refreshed approach to delivering carbon capture and storage (CCS) in the UK, recommending an initial focus on one or two clusters of industry and the need to deal separately with investment in transport and storage infrastructure if a CCS network is to be established.

The Scottish case study has a wider significance for the UK and Europe. The scenarios presented could provide around half of the CO2 capture considered necessary by the CCC for a scaled roll-out of a developing UK CCS industry by 2035, which would deliver key learning and help to reduce costs further.

Key recommendations from the study

• The SCCS study, which looked at CO2 capture quantities, capture project costs and transport connection costs to storage for 13 industry and power facilities in Central Scotland, suggests that:

• Scotland's legacy of gas pipelines offers a way to reduce the capital cost of CO2 transport from clusters of large-point sources, such as power plants, refineries and chemicals and cement manufacturers.

• Specifically, the Feeder 10 gas pipeline could collect and transport between 3.5 million tonnes per year (Mt/yr) of CO2, its basic capacity, and 10 Mt/yr of CO2, its maximum capacity, captured from different Scottish industrial clusters.

• The Grangemouth industrial complex has the greatest concentration of emissions and short connection routes to Feeder 10. Annually, it could capture and deliver around 2 million tonnes (Mt) of CO2, with scope to increase that volume by 3.8 Mt/yr if Summit Power goes ahead with the proposed Caledonia Clean Energy Project.

• A second collection network covering Fife and the upper Forth area could collect 1.7 Mt of CO2 annually.

• Around 80% of Scotland's large-point sources of CO2 emissions are within 40km of the Feeder 10 pipeline. Re-use of this pipeline would roughly halve the capital cost of transporting these CO2 volumes from Central Scotland to St Fergus in the north east for connection to offshore storage facilities.

The Central North Sea has the largest and best understood CO2 storage capacity in Europe; this has been shown to be ready for commercial development by recent projects [CO2MultiStore and Strategic UK CO2 Storage Appraisal Project]. Developing capture clusters along the eastern seaboard of the UK and reusing existing onshore and offshore pipelines can help commercialise this storage resource rapidly, with benefits for the environment and the economy from a new offshore CO2 storage industry.

Dr Peter Brownsort, lead author of the study and SCCS Scientific Research Officer, said: "The UK has a pressing need to clarify its pathway to decarbonisation under the terms of our 2008 Climate Change Act and, more recently, from our commitment to the Paris Agreement on climate action. The findings of our work support recommendations made recently by the Committee on Climate Change, which is calling on the UK Government to develop a new strategy for CCS in the UK immediately.

"Our study shows that it is possible to capture and transport significant amounts of CO2 from industrial clusters in Scotland right now, with known technology and by converting existing infrastructure. The presence of existing pipelines, both on and offshore, available for reuse can bring direct savings to CCS projects."

"This unique advantage, combined with the huge CO2 storage potential in the Central North Sea, makes a strong case for initiating a CO2 capture cluster and transport network in Scotland, which could lead to commercialisation of a new offshore CO2 storage industry serving the UK and Europe."

The SCCS paper, Reducing costs of Carbon Capture and Storage by shared reuse of existing pipeline – case study of a CO2 capture cluster for industry and power in Scotland, is published in the International Journal of Greenhouse Gas Control and can be downloaded free until 3 September 2016

More information

www.sccs.org.uk

CO2 fingerprint discovery enables safe storage of greenhouse gas

Scientists from the University of Edinburgh have found an inexpensive way to help monitor the safe storage of carbon dioxide captured from power stations and industrial sources.

In the first study of its kind, researchers have discovered that CO2 captured from power stations and industrial sites will have a distinctive chemical fingerprint, depending on its source. This allows it to be distinguished from other CO2 present near storage sites, such as groundwater or naturally occurring CO2 given off by plants and bacteria.

This means that CO2 being injected deep underground does not need to have expensive chemical tracers added, in order to monitor that it is effectively contained.

Researchers from the University of Edinburgh found that the natural fingerprint of captured CO2 depends on the fuel producing the gas - such as coal, oil, natural gas or biomass - and the technology being used to capture it before it is injected for underground storage.

By comparing the chemical fingerprints in the captured CO2 with those in geological storage reservoirs and drinking water aquifers, they have been able to show that the fingerprints can be easy to identify and distinguishable from natural sources of CO2.

The study, published in Environmental Science and Technology, was supported by the Engineering and Physical Sciences Research Council.

Dr Stephanie Flude, of the University of Edinburgh's School of GeoSciences, who led the study, said: "Defining these natural fingerprints in captured CO2 will simplify the monitoring of geological CO2 storage sites. This method is inexpensive as it removes the need to add additional expensive artificial tracers to the CO2 being stored."

Dr Stuart Gilfillan and Dr Steph Flude collect CO2 samples at a pilot facility

Dr Stuart Gilfillan, also of the School of GeoSciences, the study co-ordinator, said: "There has been a pressing need to identify a means to distinguish CO2 to be stored from that already in the subsurface to help CCS deployment. Our study shows that natural fingerprints in the captured CO2 are unique and depend on the capture technologies being used. This paves the way for natural fingerprints to be used to track the CO2 once it is injected underground for storage."

More information

www.sccs.org.uk

CO_2 stored ten times longer than needed

A Cambridge University study of naturally occurring 100,000 year old CO_2 reservoirs shows no significant corroding of cap rock, suggesting the gas hasn't leaked.

The research shows that natural accumulations of carbon dioxide (CO_2) that have been trapped underground for around 100,000 years have not significantly corroded the rocks above, suggesting that storing CO_2 in reservoirs deep underground is much safer and more predictable over long periods of time than previously thought.

These findings, published in the journal Nature Communications, demonstrate the viability of CCS as a solution to reducing carbon emissions from coal and gas-fired power stations, say researchers.

The CO_2 must remain buried for at least 10,000 years to avoid the impacts on climate. One concern is that the dilute acid, formed when the stored CO_2 dissolves in water present in the reservoir rocks, might corrode the rocks above and let the CO_2 escape upwards.

By studying a natural reservoir in Utah, USA, where CO_2 released from deeper formations has been trapped for around 100,000 years, a Cambridge-led research team has now shown that CO_2 can be securely stored underground for far longer than the 10,000 years needed to avoid climatic impacts.

Their new study shows that the critical component in geological carbon storage, the relatively impermeable layer of "cap rock" that retains the CO_2, can resist corrosion from CO_2-saturated water for at least 100,000 years.

"Carbon capture and storage is seen as essential technology if the UK is to meet its climate change targets," says principle investigator Professor Mike Bickle, Director of the Cambridge Centre for Carbon Capture and Storage at the University of Cambridge.

"A major obstacle to the implementation of CCS is the uncertainty over the long-term fate of the CO_2 which impacts regulation, insurance, and who assumes the responsibility for maintaining CO_2 storage sites. Our study demonstrates that geological carbon storage can be safe and predictable over many hundreds of thousands of years."

The key component in the safety of geological storage of CO_2 is an impermeable cap rock over the porous reservoir in which the CO_2 is stored. Although the CO_2 will be injected as a dense fluid, it is still less dense than the brines originally filling the pores in the reservoir sandstones, and will rise until trapped by the relatively impermeable cap rocks.

"Some earlier studies, using computer simulations and laboratory experiments, have suggested that these cap rocks might be progressively corroded by the CO_2-charged brines, formed as CO_2 dissolves, creating weaker and more permeable layers of rock several metres thick and jeopardising the secure retention of the CO_2," explains lead author Dr Niko Kampman.

"However, these studies were either carried out in the laboratory over short timescales or based on theoretical models. Predicting the behaviour of CO_2 stored underground is best achieved by studying natural CO_2 accumulations that have been retained for periods comparable to those needed for effective storage."

To better understand these effects, this study, funded by the UK Natural Environment Research Council and the UK Department of Energy and Climate Change, examined a natural reservoir where large natural pockets of CO_2 have been trapped in sedimentary rocks for hundreds of thousands of years. Sponsored by Shell, the team drilled deep down below the surface into one of these natural CO_2 reservoirs to recover samples of the rock layers and the fluids confined in the rock pores.

The team studied the corrosion of the minerals comprising the rock by the acidic carbonated water, and how this has affected the ability of the cap rock to act as an effective trap over geological periods of time. Their analysis studied the mineralogy and geochemistry of cap rock and included bombarding samples of the rock with neutrons at a facility in Germany to better understand any changes that may have occurred in the pore structure and permeability of the cap rock.

They found that the CO_2 had very little impact on corrosion of the minerals in the cap rock, with corrosion limited to a layer only 7cm thick. This is considerably less than the amount of corrosion predicted in some earlier studies, which suggested that this layer might be many metres thick.

The researchers also used computer simulations, calibrated with data collected from the rock samples, to show that this layer took at least 100,000 years to form, an age consistent with how long the site is known to have contained CO_2.

The research demonstrates that the natural resistance of the cap rock minerals to the acidic carbonated waters makes burying CO_2 underground a far more predictable and secure process than previously estimated.

"With careful evaluation, burying carbon dioxide underground will prove very much safer than emitting CO_2 directly to the atmosphere," says Bickle.

The Cambridge research into the CO_2 reservoirs in Utah was funded by the Natural Environment Research Council (CRIUS consortium of Cambridge, Manchester and Leeds universities and the British Geological Survey) and the Department of Energy and Climate Change.

The project involved an international consortium of researchers led by Cambridge, together with Aarchen University (Germany), Utrecht University (Netherlands), Utah State University (USA), the Julich Centre for Neutron Science, (Garching, Germany), Oak Ridge National Laboratory (USA), the British Geological Survey, and Shell Global Solutions International (Netherlands).

More information

Cambridge Centre for Carbon Capture and Storage:

www.ccs.cam.ac.uk