Carbon Capture Journal

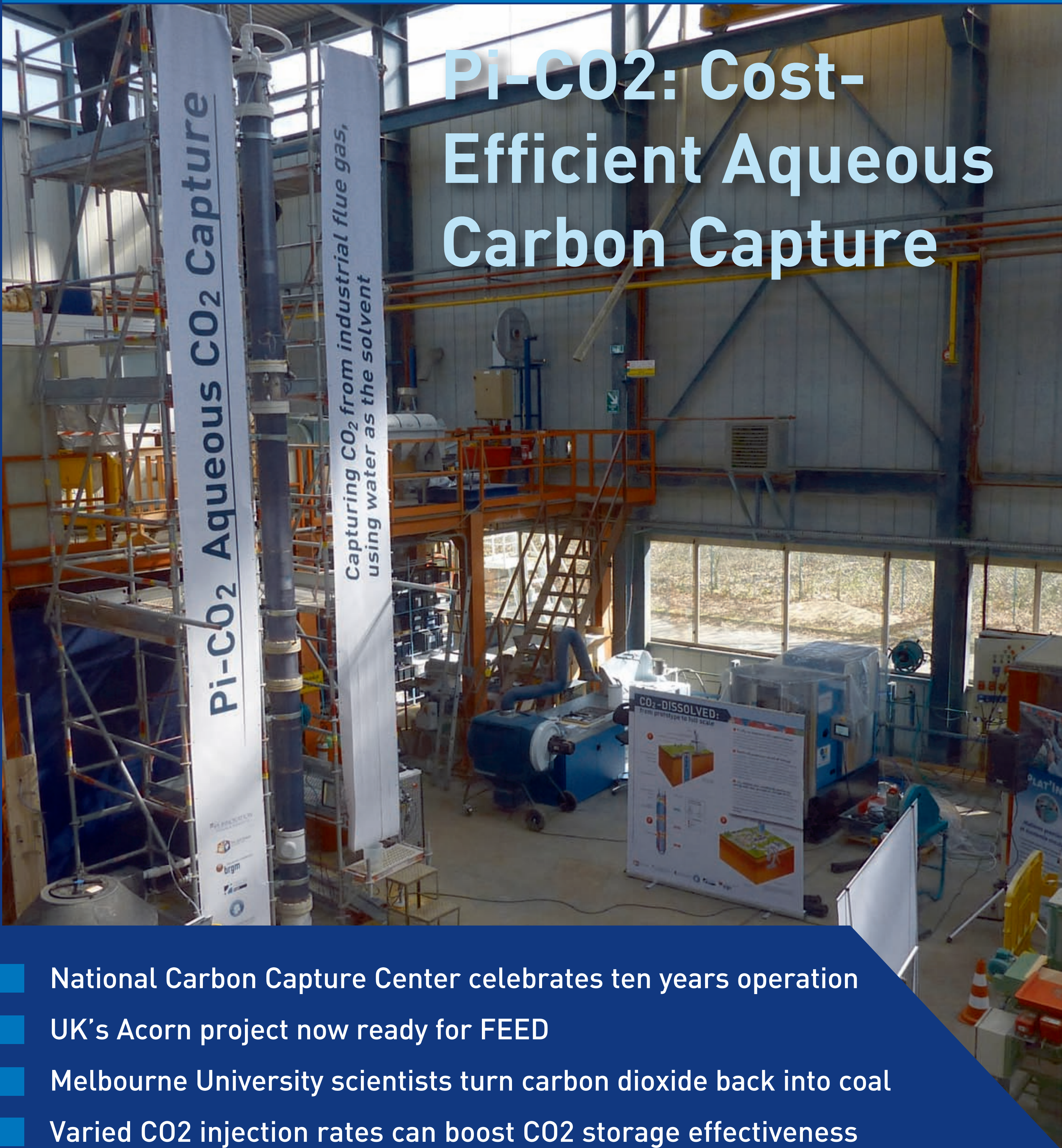
CCUS in the U.S.

Section 45Q Tax Credits explained

ROTA-CAP rotating bed carbon capture process

BIGs: environmentally friendly sorbents

Mar / Apr 2019 Issue 68



Pi-CO2: Cost-Efficient Aqueous Carbon Capture

- National Carbon Capture Center celebrates ten years operation
- UK's Acorn project now ready for FEED
- Melbourne University scientists turn carbon dioxide back into coal
- Varied CO2 injection rates can boost CO2 storage effectiveness

Introducing CO2RE: The world's first global CCS intelligence database

The launch of the CO2RE CCS Intelligence Database represents a significant evolution of the Global CCS Institute's vast CCS knowledge and data repository.

CO2RE is the world's first global CCS intelligence database. It puts core information on CCS at your fingertips, and could become the pre-eminent choice for CCS information, due to its capacity to provide:

• A unified experience for Global CCS Institute Members

• Unrivalled knowledge of all aspects of CCS

• Unique insights into global and country-specific data

• Analysis to rapidly track and monitor the global development and deployment of CCS.

CO2RE is a complete knowledge management resource that organises, maintains, and makes accessible all key information and data related to the global deployment of CCS. CO2RE delivers an unparalleled resource, empowering our Members to make informed business decisions working towards accelerating the deployment of CCS as a vital climate change mitigation technology.

Here is a summary of what is available within the CO2RE database across three key areas: advocacy, analysis and knowledge.

Advocacy

The Institute is foremost about CCS advocacy; promoting CCS as a critical low emissions technology and we are committed to ensuring that CO2RE plays a crucial role in achieving this.

The publicly available CO2RE website provides information demonstrating that CCS is needed, it is happening, and it is ready for wide-scale deployment. The public can view CCS facilities, climate change data and the high-level results of the CCS Readiness Index that highlights nation's progress towards CCS deployment.

"The Facilities Database within CO2RE is where the true breadth of knowledge and detail lies," said Global CCS Institute's Advisor - CCS Projects, Harry Liu. "Over four decades of data and information is captured in this one section. Any CO2RE user can rapidly identify all CCS activity in a single country from large-scale facilities through to test sites or even CO2 utilisation projects".

Analysis

The Global CCS Institute's CCS Readiness Index is one of its premier publications. Through CO2RE, the analysis behind the Index is now readily available to Members.

The four Indicator Reports offer a detailed examination and assessment of:

• National legal and regulatory frameworks

• Climate change and CCS-specific policies

• Storage resource development

• Inherent CCS interest.

The Indicators collectively form the CCS Readiness Index, which assesses a country's CCS activity and identifies those nations that are ready for CCS deployment. The four Indicators and Readiness Index can also provide data to those nations seeking to improve the development or deployment of CCS in their country.

"The Institute's CCS Readiness Index can help Members identify those nations that are creating an enabling environment for the commercial deployment of CCS," said Alex Zapantis, General Manager – Commercial.

Knowledge

"The list of CCS laws and regulations identified in each country number in the hundreds, but now they can be easily found in one place" Ian Havercroft Senior Consultant – Legal and Regulatory.

CO2RE is knowledge and, as the saying goes, knowledge is power. The amount of information available in CO2RE is too large to detail, but there are four notable areas:

• Policies: a comprehensive list of climate change and CCS-specific policies

• Law: a comprehensive list of laws and country summaries that impact CCS deployment

• CO2 storage: summary of storage resources and the maturity of those resources, as well as a list of prospective basins for CO2

• Climate Change: a single site that contains emissions of the world, including breakdown per country and sector. Also hosting the UNFCCC pledges and emission reduction goals for over 50 countries.

What's next?

"It is clear that CO2RE represents one of the most valuable Member resources we have ever developed," said the Institute. "We are incredibly excited to present our Members this database of unique CCS data, knowledge and information. More importantly, we are excited to see what amazing things our Members do with CO2RE and how it can help you, and your organisation, accelerate the global deployment of CCS."

Reliable data, analysis and knowledge on CCS are vital to understanding how the technology can reduce emissions, deliver Paris climate change targets and create new energy economies.

More information

www.globalccsinstitute.com

Carbon Capture Journal

Mar / Apr 2019 Issue 68

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Front cover:

The Pi-CO2 cost-efficient aqueous carbon capture system offers capture for less than $31 per tonne including compression to pipeline pressure. (Image: ©BRGM Rowena Stead)

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

Leaders - CCUS in the U.S.

Projects and policy

Capture and utilisation

Transport and storage

Nuts and bolts of Section 45Q Tax Credits

CCUS projects in the United States will increase due to changes in a powerful tax incentive.
By Keith Tracy, President, Cornerpost CO2 LLC.

One of the major hurdles precluding more carbon capture projects is insufficient economic returns. To address this concern, the US has sought to enact various policies encouraging CCUS projects, including adopting the Section 45Q income tax credit.

Through the recent revision and expansion of the Internal Revenue Service (IRS) Code Section 45Q income tax credit, significant incentives are now available to numerous carbon capture and storage projects in the United States. The tax credits, awarded based on the volume of CO2 captured and stored, are worth up to US $50 per tonne.

While Section 45Q was adopted over 10 years ago, very few projects qualified under the old system, in part because the entire program would sunset after a nationwide aggregate of 75 million tonnes were sequestered. In addition, the minimum sized project had to capture at least 500,000 tonnes per year, and many considered the value of the credits (approximately US $10-$20 per tonne) to be too low to provide sufficient incentive to act.

Under the new law adopted February 9, 2018, the nationwide aggregate limitation was eliminated for new projects, and the minimum sized project was reduced to 100,000 tonnes per year (and in some instances, only 25,000 tonnes per year). Additionally, Section 45Q has been expanded to include carbon monoxide (not just CO2), and approved storage methods now include permanently fixing the gas in a commercial product (in addition to storage underground).

What qualifies?

Many sources of carbon emissions qualify for the 45Q tax credit. The CO2 must be captured from a fuel combustion source, a manufacturing process, or a fugitive CO2 emission source. For example, facilities that produce power, ethanol, cement, fertilizer, methanol, steel, chemicals, and industrial gases all qualify, as well as refineries, natural gas processing plants, and direct air capture facilities.

For power plants, at least 500,000 tonnes of CO2 per year must be captured to qualify for the 45Q credit (and that requirement may only apply to power plants selling at least half their power on the grid). All other facilities only have to capture 100,000 tonnes per year, which is equivalent to an average of about 5,500 mcf per day.

Credits are also authorized if the CO or CO2 is "utilized" or permanently fixing the gas in a commercial product, such as growing algae or forming a chemical compound. In most of those instances, the minimum threshold to capture for 45Q tax credits is only 25,000 tonnes per year. For these "utilization" technologies, an analysis is required to determine the quantity that was either permanently isolated from the atmosphere, or displaced from being emitted to the atmosphere.

The 45Q tax credits are awarded to the owner of the carbon capture equipment. The owner can contract with a third-party to physically inject the CO2 underground, or the owner can be the one to inject the carbon. If the owner desires, it can elect to transfer the credit to the third-party injection company.

The 45Q tax credit is available for up to 12 years for new carbon capture projects. That 12-year time period begins on the date the carbon capture equipment is first placed into service. As a business credit, the 45Q tax credits earned in one year can be applied in another year: it can be carried back 1 year and can be carried forward for up to 20 years.

There is a deadline for starting construction on new qualifying projects. The 45Q law currently requires that carbon capture equipment must at least begin construction before January 1, 2024.

In instances where a new power plant or industrial facility is being built, 45Q appears to be available if both (a) the power plant or industrial facility begins construction by that date and (b) the design of that plant/facility includes the future installation of carbon capture equipment (even if construction of that equipment is not begun by the deadline).

45Q requires CO2 injected underground to be permanently sequestered, or placed into what the law requires "secure geologic storage". Approved locations include oil and gas reservoirs, deep saline formations, and unminable coal seams.

As a result, enhanced oil recovery (EOR) and enhanced gas recovery (EGR) are approved methods that qualify as "secure geologic storage" of CO2. Providing flexibility, 45Q does not specify use of any particular classification of injection well under the US Environmental Protection Agency (EPA) program for Underground Injection Control (UIC).

The IRS has previously interpreted "secure geologic storage" to mean that injection operations must comply with the Greenhouse Gas (GHG) Reporting Rule adopted by EPA. Subpart RR of that Rule requires reporting GHGs from facilities that inject CO2 underground for geologic sequestration.

It also requires operators to obtain EPA approval of a "monitoring, reporting and verification" (MRV) plan for each project.

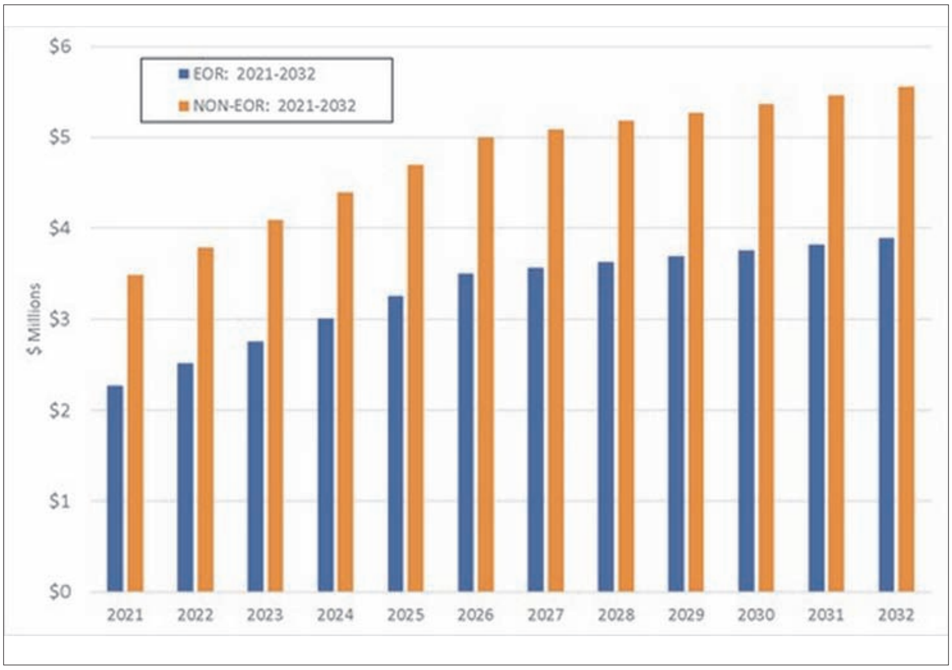
An IRS internal memo released last year contained a recommendation to disallow 45Q tax credits in a case where an EOR operator chose not to follow Subpart RR rules and did not obtain EPA approval of an MRV plan. The IRS may choose to provide additional guidance on what is required to demonstrate permanence or "secure geologic storage".

Value of the credit

The value of the 45Q tax credit falls into two categories, based on where the carbon is stored. The first category is for CO or CO2 that is "utilized" to make a product, or is injected underground for enhanced oil/gas recovery. The 45Q credit value for this first category is US $17.76 per tonne in 2019, and gradually increases by about US $2.50 per year up to US $35 per tonne in 2026.

The second category of 45Q credit value is for underground injection of carbon into a formation other than EOR/EGR. The 45Q credit value for this second category is higher, is US $28.74 per tonne in 2019, and gradually increases by about US $3.00 per year up to US $50 per tonne in 2026. After 2026, both categories of credit values are adjusted based on an inflation factor.

As an example (depicted in the chart), a 45Q tax credit project that captures the minimum of 100,000 tonnes per year from an industrial facility, and begins capture and injection operations in 2021 into an EOR formation, will generate a total of approximately US $40 million over the course of 12 years (from 2021-2032), assuming 1.5% inflation. If that same project injected the CO2 into a saline aquifer instead of EOR, the 45Q tax credits would total about US $57 million.



The US 45Q tax credit values increase over time, and is lower for geologic storage of CO2 associated with EOR/EGR operations (values beyond 2026 assume a 1.5% inflation rate)

Requirements

Many additional requirements are imposed by Section 45Q and IRS interpretations. For example, annual reports must be filed with the IRS. 45Q only applies to carbon captured and sequestered in the US. Also, special rules apply for "applicable facilities" which are older carbon capture projects that did not claim credits under the old law. Advice of a tax attorney or 45Q consultant is recommended for all projects seeking to qualify for Section 45Q tax credits.

It is anticipated that the IRS will soon be adopting additional and revised guidance on various aspects of the Section 45Q tax credits. The IRS may borrow some concepts from US wind and solar tax credits regarding what actions are sufficient to "begin construction" of an industrial facility or carbon capture equipment. Additional methods of demonstrating "secure geologic storage" may also be recognized. The concepts of "utilization" and direct air capture facilities were added to 45Q in the recent amendments, so future IRS guidance could address those topics as well.

Section 45Q tax credits present an extensive motivation to capture and sequester carbon. Whether the CO or CO2 is "utilized" and stored in a product, or is sequestered underground in a geologic formation, the expanded incentive is sure to stimulate activity in the US carbon capture industry.

More information

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CO2 Capture Going BIG

A new class of sorbents called bis-iminoguanidines (BIGs) have been developed which are environmentally friendly and have lower energy requirements compared to traditional carbon capture technologies.

Neil J. Williams and Radu Custelcean, Oak Ridge National Laboratory

"Currently, the world is way off track in meeting the Paris Agreement climate goals. It cannot get back on track without CCS". This statement, issued by the Global CCS Institute in its recent report on The Global Status of CCS (Carbon Capture and Storage),[i] underlines the importance of developing new methods and technologies to reduce the amount of greenhouse gases in the atmosphere.

Since the beginning of the industrial revolution, the atmospheric CO2 concentration has increased from 280 to 410 parts per million (ppm), which is a 46% increase. Most of the added CO2 can be attributed to fossil fuel emissions from energy production (i.e., burning coal, natural gas, and oil) and other industries (e.g., cement, steel). The CO2 level will likely continue to rise in the coming decades, as the world population and the energy consumption continue to increase and rely on fossil fuels.

While the Earth's ecosystems have mechanisms for reducing the amounts of CO2 present in the atmosphere, absorbing roughly half of our annual emissions, the other half, consisting of about 18 gigatonnes of carbon dioxide per year, will have to be addressed through CCS technologies. Meanwhile, the global average temperature has already risen about 1°C over the course of the 20th century, and will likely exceed the 1.5°C increase limit in a few decades.

Indeed, as the Earth is out of energy balance with the current atmospheric composition, there is more warming in the pipeline even if the global emissions were to be cut to zero today. A recent report from the U.S. National Academy of Sciences[ii] concluded that limiting the increase in the global temperature to less than 2°C by the end of this century becomes exceedingly challenging without large-scale deployment of Negative Emissions Technologies (NETs).

NETs, such as Direct Air Capture (DAC), remove CO2 out of the atmosphere, in effect reducing past emissions. They also can address dispersed emissions from transportation and buildings, which currently account to about 50% of global annual emissions.

In this article, we will discuss a CO2-capture technology, currently under development at Oak Ridge National Laboratory (ORNL), designed to remove carbon dioxide from both point sources (i.e., flue gas), and directly from the atmosphere (i.e., DAC), using a new class of sorbents called bis-iminoguanidines (BIGs). This emerging technology is environmentally friendly and has lower energy requirements compared to traditional carbon capture technologies.

The technologies most commonly employed to date for CO2 capture are based on two classes of sorbents: liquid sorbents, also called solvents, and solid sorbents.[iii] Both classes have advantages and disadvantages when it comes to CO2 separations from point sources or from air. The technologies based on liquid sorbents use one of two types of solvents: aqueous inorganic bases (e.g., sodium hydroxide, potassium hydroxide), or aqueous organic amines (e.g. monoethanolamine (MEAs)).

With both types of solvents, the uptake of CO2 occurs rapidly due to favorable kinetics for converting the CO2 into either (bi)carbonate or carbamate ions. However, in both cases the CO2 release and sorbent regeneration require significant amounts of energy, mostly connected to heating and evaporating water. To avoid this energy penalty, in the case of aqueous alkaline bases, the resulting carbonate anions are precipitated as insoluble calcium carbonate, which can be filtered and removed from solution, and then heated to over 800°C in an oxygen atmosphere to release the CO2 and regenerate the alkaline sorbent.

Such high temperatures are difficult to achieve without using fossil-fuel energy sources, and the resulting CO2 emissions partly offset the CO2 captured, significantly reducing the net amount of carbon removed. On the other hand, organic amines, such as MEA, can release the CO2 at much lower temperatures of about 100-150°C. However, a major issue with liquid amines is their high volatility and the low stability, leading after repeated cycles of capture and release to significant sorbent loss and reductions in efficiency and performance. Furthermore, the high toxicity of amines makes them environmentally harmful, and especially non-suitable for DAC applications.

Compared to liquid sorbents, solid sorbents have been far less employed in carbon capture technologies, although they have been the subject of many academic studies in the last couple of decades. They are typically porous materials, such as zeolites, metal-organic frameworks, silica, activated carbon, etc., and can bind the CO2 either by physisorption, or chemisorption. The latter mechanism is usually achieved by pore functionalization with amine groups, which bind the CO2 strongly and selectively, as required in carbon capture applications involving more dilute CO2 sources, such as air.

Though they typically have lower rates of CO2 uptake than aqueous sorbents, solid sorbents have the advantage of lower energies of regeneration and CO2 release as a result of lower heat capacities. However, water can condense inside the pores during the CO2 absorption, resulting in an energy penalty associated with water desorption during the

i The Global Status of CCS, Global CCS Institute, 2018, www.globalccsinstitute.com/resources/global-status-report/

ii National Academies of Sciences, Engineering, and Medicine. 2018. Negative Emissions Technologies and Reliable Sequestration: A Research Agenda. Washington, DC: The National Academies Press. doi: https://org/10.17226/25259.

iii US Department of Energy. 2018. Accelerating Breakthrough Innovation in Carbon Capture, Utilization, and Storage. www.energy.gov/fe/downloads/accelerating-breakthrough-innovation-carbon-capture-utilization-and-storage

CO2 release. Another significant issue with solid sorbents is that their pores can get blocked or collapse after repeated sorption-desorption cycles, leading to decreasing capacities and flow rates over time.

Furthermore, heat transfer through solids is slow and inefficient, making it difficult and expensive to cool and heat up the sorbent during the adsorption and desorption of CO2, respectively. Finally, the manufacture costs of solid sorbents tend to be much greater than the corresponding costs of liquid sorbents discussed in the prior paragraph.

Carbon capture technologies can be applied to gas streams of various CO2 concentrations, ranging from about 0.04% in air, to about 5-13% in industrial flue gases. While the sorbents used and the methods applied are similar, every application may impose its specific constraints. For instance, flue gases from power plants are best treated using liquid amine sorbents because of the need for fast kinetics, high CO2 loading capacities, and high CO2 removal fraction (typically 90% or higher CO2 removal is required).

Direct air capture of CO2, on the other hand, is an inherently open process, which prohibits the use of volatile and toxic liquid amines. In this respect, solid-supported amines are more suitable, though they still have the issues of poor stability and decreased performance over time. Alternatively, aqueous alkaline sorbents (e.g., potassium hydroxide) can be used for DAC, though high sorbent regeneration energies and temperatures remain unresolved issues.

Our CO2 capture technology is based on a hybrid solvent/solid sorbent approach combining liquid-phase CO2 absorption with solid-state CO2 release. As such, it combines the best of the two worlds: relatively fast absorption rates, easy handling, and low maintenance, characteristic to aqueous sorbents, with lower regeneration energies and minimal sorbent loss through evaporation or degradation, typical for solid sorbents.

The sorbents are a class of organic molecules, called bis-iminoguanidines (BIGs), first synthesized and reported in the chemical literature by German scientists at the end of the 19th century. We recently recognized the ability of BIGs to strongly bind to anions (negatively charged molecules) and separate them from water by selective crystallization.

It follows that the anion-separation ability of BIGs can be exploited for CO2 capture via crystallization of (bi)carbonate anions that form when carbon dioxide dissolves into aqueous alkaline solutions.[iv] Thus, an aqueous BIG solution can be used as a liquid sorbent, which grabs CO2 from the gas phase and converts it into insoluble (bi)carbonate crystals. The crystals are then simply removed from solution by filtration and heated at relatively mild temperatures (80-120°C) to release the CO2 and regenerate the BIG sorbent, which can be recycled (Figure 1).[v]

This method works well with both concentrated CO2 streams, such as flue gas mixtures (12-15% CO2) and dilute ones, such as air (0.04% CO2). Because the CO2 is released in the solid-state, thereby avoiding heating and evaporating water, the energy required to regenerate the sorbent can be significantly lower (by as much as 24%) than the regeneration

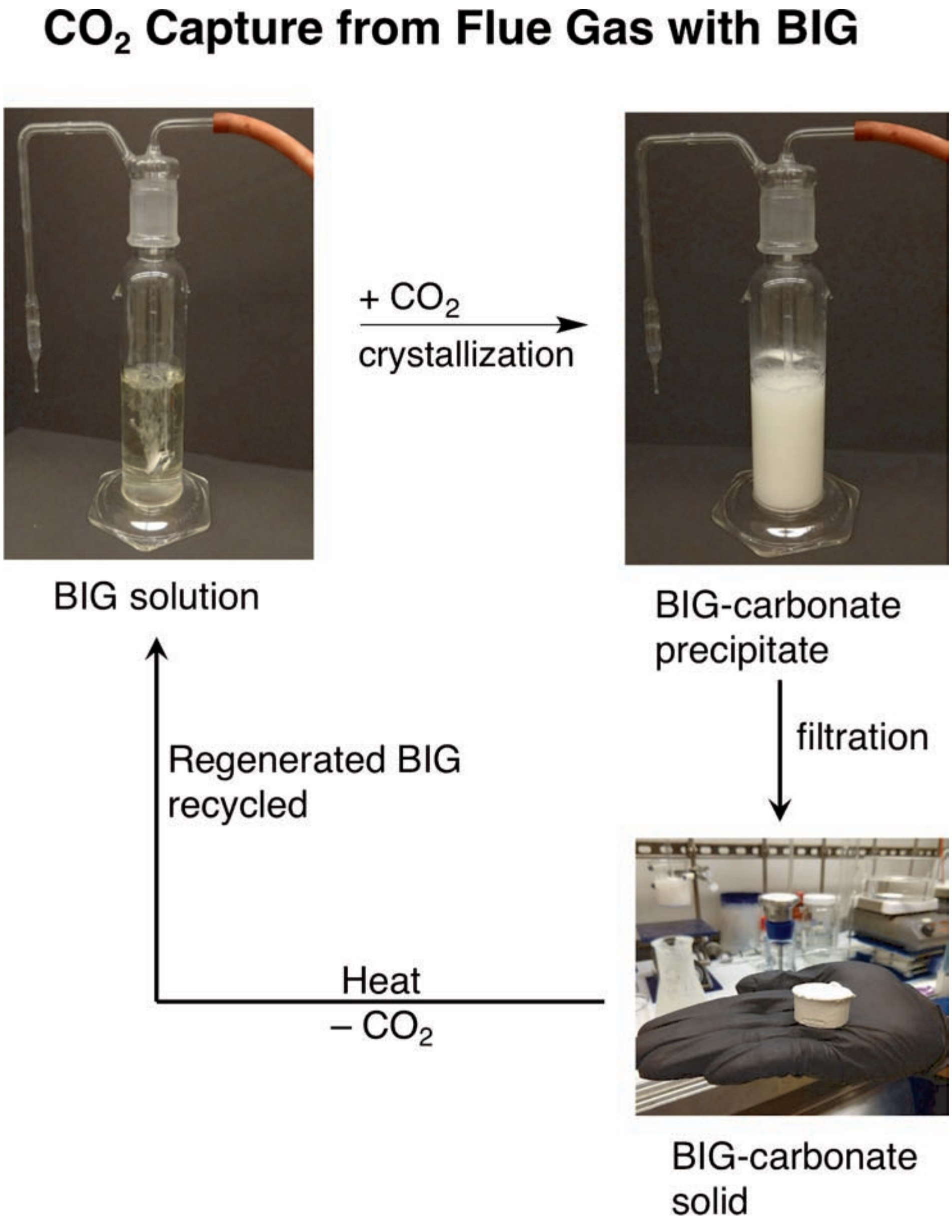

Figure 1 - CO2 separation via BIG crystallization. A flue gas simulant (12.8% CO2, EPA standard) was bubbled through the aqueous BIG sorbent, leading to crystallization of BIG carbonate. The solid was collected by filtration, then heated around 120°C to release the CO2 and regenerate the BIG

iv Seipp, C.A., Williams, N.J., Kidder, M.K., and Custelcean, R. 2017. CO2 capture from ambient air by crystallization with a guanidine sorbent. Angew. Chem. Int. Ed. 56, 1042-1045. DOI: 10.1002/anie.201610916.

v Williams, N. J.; Seipp, C. A.; Brethomé, F. M.; Ma, Y.-Z.; Ivanov, A. S.; Bryantsev, V.; Kidder, M. K.; Martin, H. J.; Holguin, E.; Garrabrant, K. A.; Custelcean, R. CO2 Capture via Crystalline Hydrogen-Bonded Bicarbonate Dimers. Chem 2019, DOI: 10.1016/j.chempr.2018.12.025.

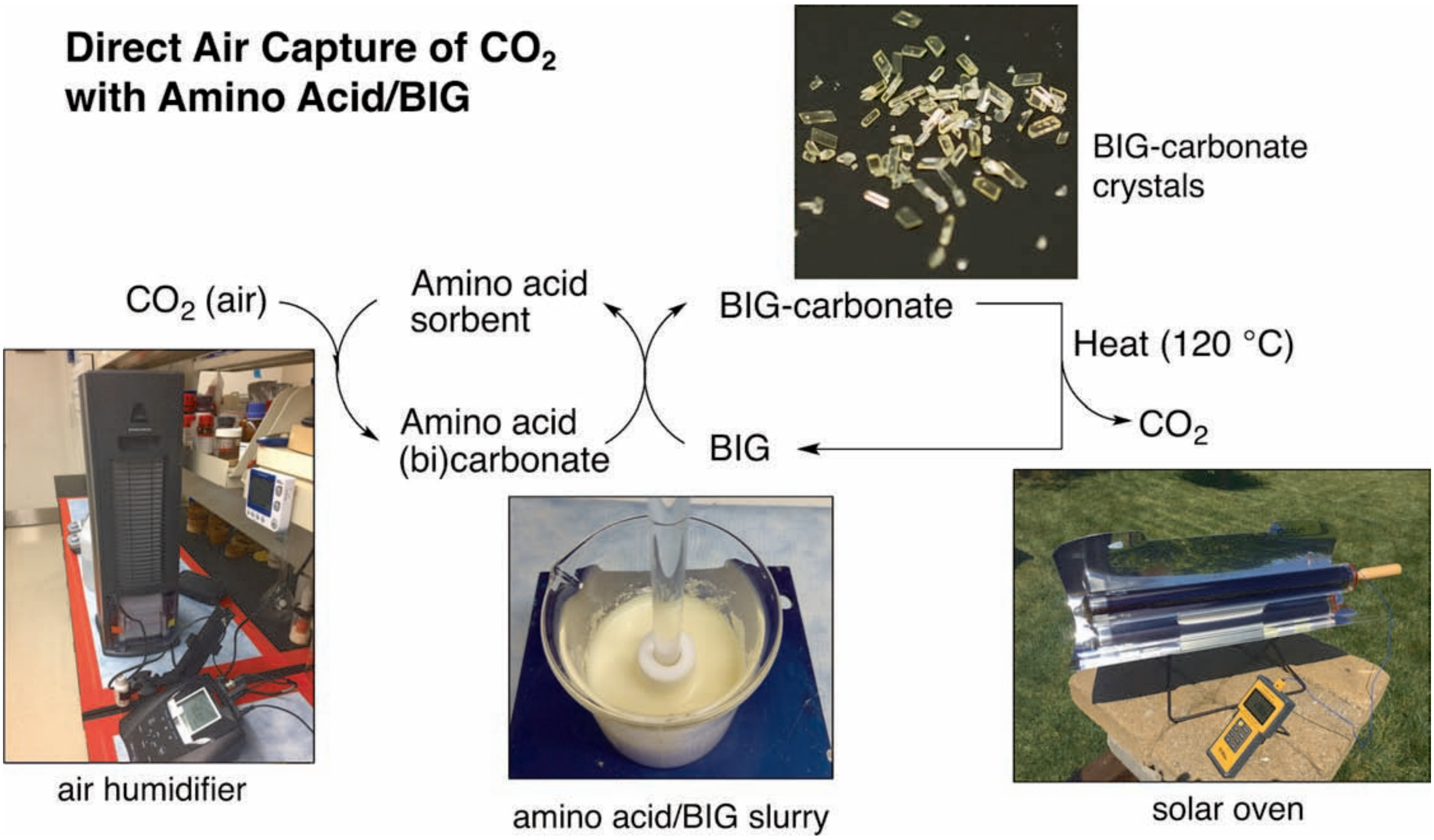

Figure 2 - Direct air capture of CO2 by absorption with amino acids and crystallization with BIGs. A household air humidifier was employed as an air-liquid contactor, and a commercial solar cooker was used to release the CO2

energy of industrial benchmark sorbents like aqueous MEA.

Unlike amines, the BIG sorbents are also remarkably stable, showing no sign of decomposition even after heating in the air at 120°C for a week. However, due to their low aqueous solubilities, BIGs have relatively low CO2 loading capacities and absorption rates. To address this limitation, we developed a two-cycle process where the CO2 is initially captured by amino acid solutions, then the loaded solutions are scrubbed by mixing with a solid BIG suspension to remove the captured CO2 via crystallization (Figure 2).[vi]

In this process, the amino acid solutions convert the absorbed CO2 into bicarbonate anions, which form insoluble salts with the solid BIG and precipitate out of solution. This reaction is relatively fast, taking 30 minutes or less to complete, then the BIG carbonate crystals are removed by filtration and the amino acid solutions are recycled. Finally, the BIG carbonate crystals are heated to around 100-120°C for 1 hour to release the captured CO2 and regenerate the BIG sorbent for reuse.

The one-order of magnitude decrease in the temperature of CO2 release, compared to traditional alkaline carbonates (e.g., calcium carbonate), has major implications for the economics of the process, as much cheaper and more abundant low-grade heat can be used for sorbent regeneration, such as waste heat or heat generated from renewable sources (e.g., concentrated solar power).

To date, this novel technology has been demonstrated at the laboratory scale, using mostly off-the-shelf equipment for the initial proof of concept. For concentrated streams of CO2, we used either a fritted bubbler or a small (1.6 L) bubble reactor to load the sorbents, whereas for the direct air capture we used a household air humidifier.

The BIG carbonate crystallizations and amino acid regenerations were done in a 2 L beaker, mixing the suspensions with a mechanical stirrer. Finally, the CO2 release and BIG regeneration were demonstrated using either a laboratory oven as a conventional heat source, or a solar cooker as a renewable heat source. Up to 10 consecutive absorption/release cycles were performed, with virtually no decrease in the observed CO2-capture performance.

Moving forward, we seek to optimize and scale up this technology, and perform techno-economic analyses for both flue gas and DAC applications. Further improvements in sorbent compositions, gas-liquid contactor designs, handling of slurries and solids, heat management, and overall process design will be required to make the big step from laboratory to industrial scale. To this end, we are looking for industrial partners interested in further developing this promising CO2-capture method into a mature, energy-efficient, and cost-effective technology that can help mitigate climate change.

This research was supported by the US Department of Energy, Office of Science, Basic Energy Sciences, Chemical Sciences, Geosciences, and Biosciences Division.

More information

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vi Brethomé, F. M.; Williams, N. J.; Seipp, C. A.; Kidder, M. K. Custelcean, R. Direct Air Capture of CO2 via Aqueous-Phase Absorption and Crystalline-Phase Release Using Concentrated Solar Power. Nature Energy 2018, 3, 553-559. DOI: 10.1038/s41560-018-0150-z.

Cost-Efficient Aqueous Carbon Capture: Pi-CO2 Multi-National Prototype

For decades, the limiting condition to CO2 capture has been the 'Cost of Capture'. Over the past 10 years, Partnering in Innovation, Inc. (Pi), Savanah River National Laboratory, and others have developed a low risk system that directly addresses this, and other, limitations.

In 2018, with partnerships in the US and EU, Pi completed their first-of-a-kind prototype demonstrations in collaboration with the BRGM in France.. Also in 2018, the Australia National Low Emission Coal (ANLEC) R&D consortia completed an independent review and Techno-Economic Assessment (TEA) including comparison to an advanced amine system in a 695MW Australian coal-fired power plant.

Under conservative conditions, the TEA reports a total cost of 31/tonne USD (including product compression to pipeline pressures) with feasible design options that may lower total costs to less than $30/tonne.

In addition, Pi-CO2 also offers the potential for the pre-treatment (removal) of contaminants (i.e., SOx, NOx, and Hg) and water recovery in an initial compression step, this added value further reduces total system costs.

The innovation basis is a capture system that uses the well-proven differential solubility of gases in water across variable pressures (Figure 1) to separate and concentrate constituent gas products. The design combines water as a solvent (carbon-neutral, non-hazardous, and non-degrading) with a natural hydrostatic pressure gradient (from atmospheric pressure to higher pressure at depth in a water column) and adds the recovery of compression and heat energy (in a system drawing from Compressed Air Energy Storage or CAES).

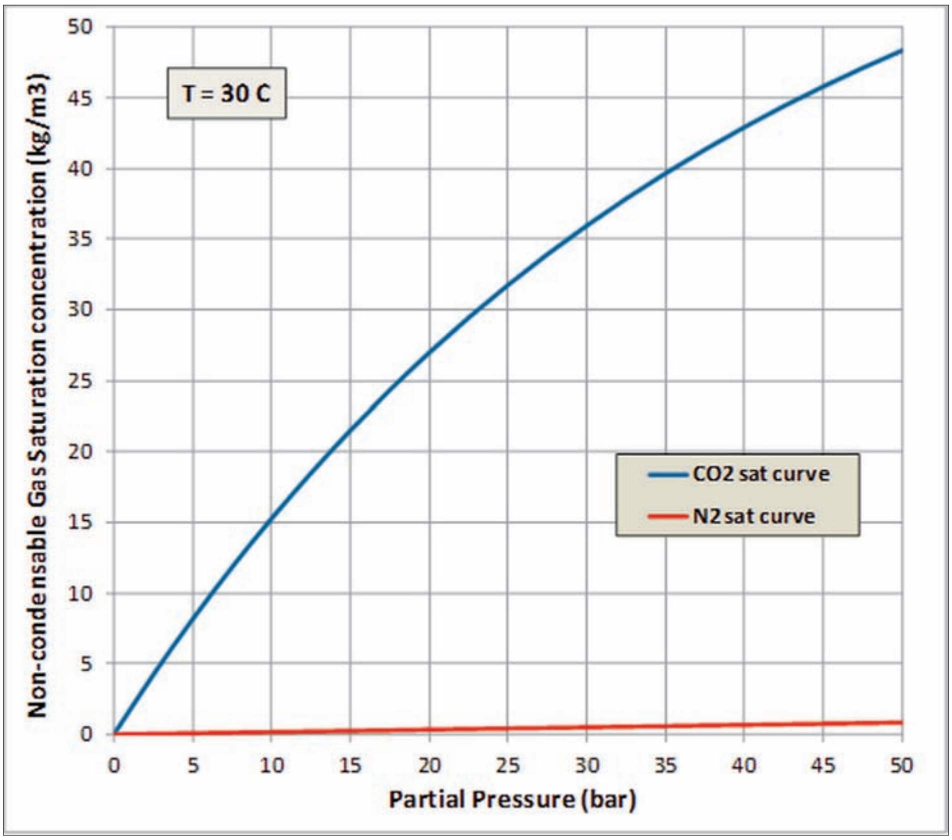

Figure 1 the well-proven differential solubility of gases in water across variable pressures

Techno-Economic Assessment (TEA)

Prior modeling confirmed thermodynamic feasibility and predicted high capture rates (>90%), efficient mass transfer (purity >95%), and high net CO2 reduction. ANLEC R&D and Aurecon Ltd Pty verified these model results and developed a parallel Aspen-PlusV10 model of the system.

The Australian setting (modeled in the ANLEC work) is in some respects a worst-case scenario for Pi-CO2. As just one example, the lack of availability/high cost of natural gas in Australia precluded the use of gas firing in the energy recovery. Even so, the TEA estimated a total cost of CO2 capture (CapEx, OpEx, including product compression to pipeline pressures) of ~31/tonne USD.

Overall, the TEA concluded that Pi-CO2 demonstrated superior benefits in: Cost, Environmental Factors, Ease in Integration, and Overall Energy Balances relative to current state-of-the-art (amine) systems.

Other TEA results suggest that the cost could be further reduced by including supplementary gas firing (in other locations where natural gas is readily available) and, potentially reduced more, by adding catalytic combustion (residual O2 + fuel) in the N2 stream, possibly reducing parasitic energy to as low as 10%.

Valuing the offset of not requiring separate SOx, NOx, and/or Hg pre-treatment systems further reduces the effective cost.

Technology Overview

The core innovation is a patented multi-stage, cascading absorber-desorber column. Adding multiple stages, with co-current flow in each stage and overall counter-current flow, utilizing a bubbly flow regime that enhances mass transfer and overcomes the thermodynamic limits of a single stage.

The concept is elegant in its low complexity (i.e., preferentially dissolving CO2 in water at high pressure) but the

design and fluid dynamics required to efficiently separate a gas mixture within the absorber are quite advanced. The concept draws from bubble, fluid, and mass transfer dynamics from nuclear, wastewater, chemical, and geologic engineering R&D. The pre-treatment steps draw from industrial gas processes and the reduction in parasitic energy is an innovative blend of heat and pressure energy recovery similar to CAES.

In general, the system can be conceptualized as 'above surface', and 'below surface' components (Figure 2). Flue gas is compressed prior to injection (at depth) into the multi-stage column which is suspended in a closed, water-filled shaft or in a deep body of water.

The initial compression step offers the option to integrate SOx, NOx, and Hg removal with minimal additional capital and operating costs. Closed-loop circulation is supported by density pumping, with no moving parts at depth.

The system preferentially dissolves CO2 in water at higher pressures, concentrating it as it moves from stage to stage in the absorber, while concurrently separating the N2.. As the dissolved CO2-enriched water travels back up the column, the CO2 is captured when it rapidly effervesces out of solution at a depth of about 50 meters (i.e., the pressure decreases as it travels up the column, releasing high purity CO2 in an exit line at a specified depth). This effervescence (ex-solution) drives the water circulation via a density buoyancy effect (similar to gas-lift pumping).

The parasitic energy burden is reduced via heat recovery from the initial flue gas compression step and compression energy recovery from the separated N2 gas stream exiting

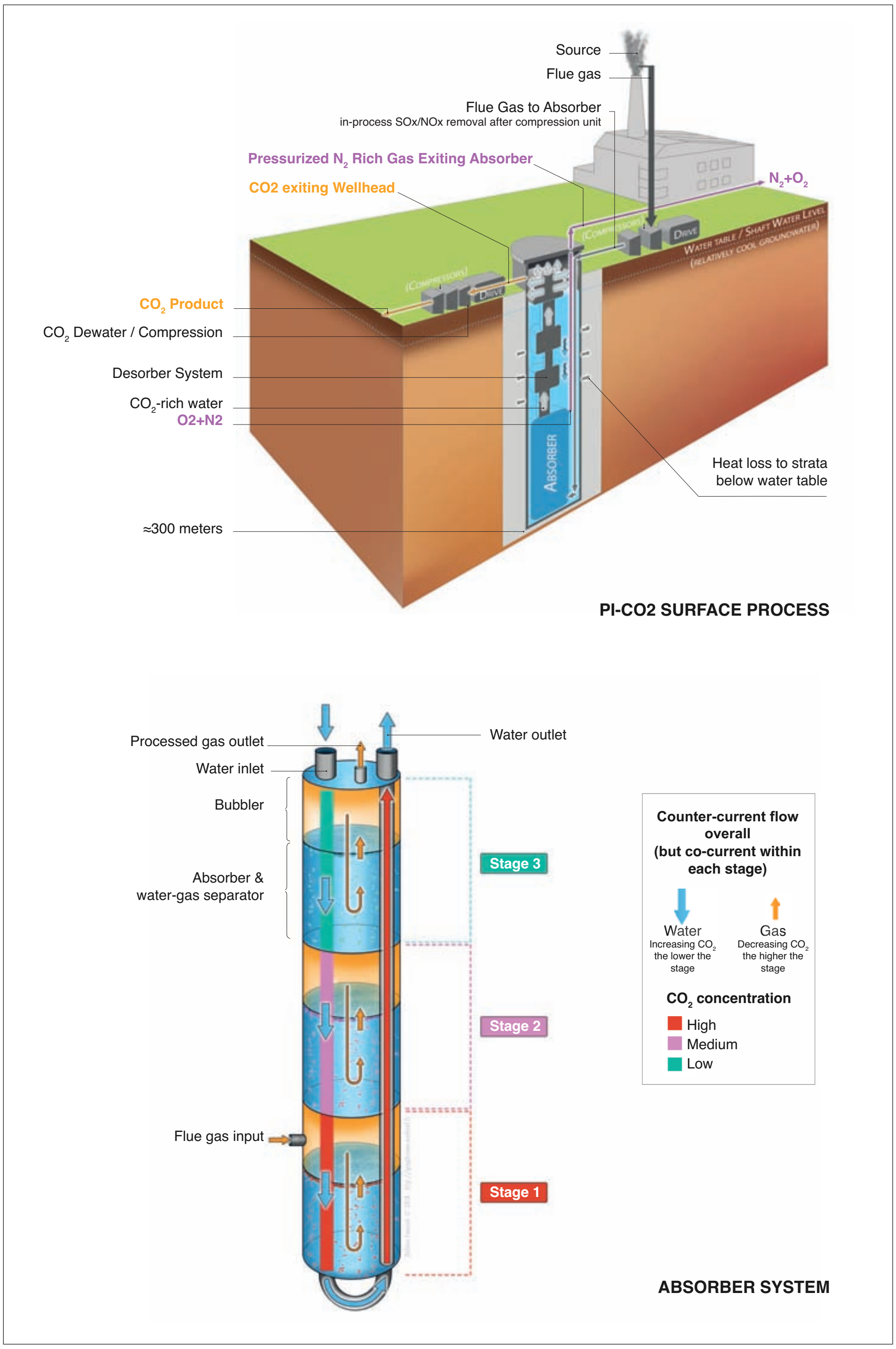

Figure 2: Pi-CO2 Surface and Subsurface System Schematic (© BRGM - Hélène Fournié 2018 http://graphisme-medical.fr)

the absorber in a CAES-like system. The system recovers both water and energy from the flue gas.

The design is low risk as the majority of the components are readily available and well-proven. The first-of-a-kind component is the absorber-desorber column. Even this is based on well-tested precursor concepts including deep shaft reactors (DSRs), down-flow bubble columns, and cascading absorbers. As example, DSRs have been used in large scale water and wastewater treatment plants to mitigate the high energy demands of mass transfer between gas and liquid phases in treatment processes. In addition, two phase natural circulation by a 'gas-lift' effect has been demonstrated in large bore DSRs, eliminating the need for additional pumping.

Some of the key design differences between Pi-CO2 and DSRs include patented features designed to achieve maximum mass transfer with dispersed bubbly downflow and an optimum balance of bubble coalescence in the riser (promoting gas lift). Other unique differences focus on the multiple stages and design parameters enhancing efficiencies.

CO2-DISSOLVED

In parallel, over the past 7+ years, Pi-Innovation has also participated as a core partner in the multi-national CO2-DISSOLVED program led by the BRGM in France (**co2-dissolved.brgm.fr**) and expanded with industry collaboration under a GEODENERGIES co-funded program.

First awarded under a competitive ANR call in 2012, CO2-DISSOLVED is a rigorous R&D program focused on a technical and financial assessment of integrating carbon capture and storage (CCS) with geothermal energy production. In this, CO2 is injected along with the spent brine in a geothermal injection well. The team is in Phase III of the GEODENERGIES program, with a current focus on the design of a pilot test.

Pi-CO2 PrototypeIn 2016, the BRGM co-funded and collaborated with Pi-Innovation and others in the development of two prototypes, one for the CO2-DISSOLVED system and one for the Pi-CO2 capture system.

A goal of the Pi-CO2 prototype testing was to confirm and optimize the design of the multi-stage absorber column. A 3-stage (~9 meters tall) absorber column was constructed in collaboration with The Tech Toybox, Inc. and Make.Work, LLC in Gainesville, Florida.

Prior sensitivity analysis of complex flow (customized code and Drift-Flux model) and thermodynamic (Aspen-Plus) system models indicated key parameters that controlled the energy and mass transfer efficiencies. In terms of the gas-liquid mass transfer in the absorber these included: flow velocity, bubble size, bubble density, and bubble flow regime.

Thus, the tests were designed to measure these parameters and the design was optimized to achieve:

• target ranges matching model prediction of high capture efficiency and product purity, and

• continuous operation with stable flow driven from stage to stage.

Figure 3 - Pi-CO2 Prototype in BRGM Laboratory (Image: © BRGM – Rowena Stead)

The system was tested sequentially – first with one stage, then two (observing flow and bubble dynamics in the transfer between stages) and finally transfer and continuous circulation between three stages. A customized automated data collection and control system provided parameter measurements and data compilation.

The prototype was then disassembled and shipped to France for re-assembly and further testing in the BRGM's laboratory facilities (Figure 3). The tests were successful in all repeated demonstrations, suggesting future success in production scale systems.

Pi-Innovation and current partners are open to expanding partnerships with prospective investors. The next step is a pressurized test of the coupled absorber-desorber, circulation, and product gas capture in a relevant environment prior to pilot testing.

More information

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ROTA-CAP rotating bed carbon capture process offers cost savings

The new ROTA-CAP process promises to change the landscape in carbon capture technology, initial estimates suggest it could slash carbon capture costs down to $30 per tonne.

Industrial facilities that use fossil fuels such as coal, natural gas and oil in their processes currently shoulder an estimated $50-75 per tonne of increased cost to remove each tonne of carbon dioxide (CO2) from the flue gas before releasing the scrubbed stream into the atmosphere.

While nearly any industrial process—manufacturing, refining and more—carries this cost and responsibility, perhaps the greatest impact is felt by the power generation industry, where, in a typical large 500 megawatt facility, millions of tonnes of flue gas need to be treated on a continuous basis to remove the CO2.

In the conventional, widely used incumbent carbon capture process, static beds packed with absorbing materials are stacked vertically in high, narrow towers, where solvents flowing from above meet the rising flue gas and remove the CO2 through acid-base chemical reactions.

Since it is a gravity-driven methodology, these towers must be dozens of feet high to accommodate the demands of the process, leading to the ubiquity of huge columns that dominate skylines around the world—as well as adding hundreds of millions of dollars in capital expenses to the upfront cost of each facility.

A new technology being developed by GTI and Carbon Clean Solutions USA Inc. (CCSUS) is looking to dramatically improve upon this incumbent process. This new integrated high gravity system - using advanced, intensified solvents - may be able to reduce carbon capture costs down to or near the U.S. Department of Energy's (DOE) aggressive goal of $30 per tonne.

In addition, the system has the potential to reduce the size of the process infrastructure needed for the gas separation by up to 90%—from dozens of feet high down to a size comparable, perhaps, to a facility's roof-top HVAC equipment—literally and figuratively changing the landscape of the industry.

Forwarding an innovative integrated technology

GTI, a leading research, development, and training organization, has been addressing global energy and environmental challenges like these for more than 75 years, often strategically partnering with innovative, like-minded public and private sector organizations in the energy industry.

These joint efforts have led to more than 1300 U.S. patents, and nearly 1400 commercialized products and licensing agreements now being used to reduce costs, improve safety, minimize environmental impacts and bolster productivity throughout industry.

CCSUS, GTI's partner in the project, is an innovative technology company providing low-cost CO2 separation materials and processes for industrial and gas treating applications. The company has extensive expertise in developing advanced solvent chemistry as well as in engineering carbon capture systems that reduce the expense and environmental impacts of CO2 capture.

Combining the complementary expertise of these two organizations, the new carbon capture technology—dubbed ROTA-CAP—has already been tested at bench scale. As the prime contractor, GTI has recently secured $2.9 million in funding from the DOE Office of Fossil Energy to prove ROTA-CAP out on a demonstration scale at a level capable of removing one ton of CO2 per day from power plant flue gas.

During the 30 month project begun in late 2018, GTI and CCSUS will design, build and operate a 1 tonne per day pilot demonstration unit to be located at GTI's Des Plaines, Illinois headquarters, after which the prototype will undergo 1000 hours of field testing with coal-fired flue gas at the DOE's National Carbon Capture Center (NCCC) in Wilsonville, Alabama. If the testing is successful it is hoped that preliminary commercialization efforts, such as a commercial scale pilot plant, could proceed thereafter.

The technology and how it works

The ROTA-CAP system replaces the static packed bed absorbers in the incumbent carbon capture process with rotating high gravity disks of packing material moving at speeds of up to 1,000 rpm, generating high centrifugal g-forces that significantly improve the mass transfer properties of the materials. In this developing application of high gravity technology, injected solvent flows from the inner edge of the rotating disk radially out to the outer edge, where it contacts the incoming CO2-containing flue gas circulating in countercurrent fashion into the disk, moving forcefully into the flow of the liquid.

The disk operation will be optimized for a new advanced solvent that is being developed exclusively for the ROTA-CAP system. As an independent developer of innovative solvents for carbon capture applications, CCSUS has upgraded clients using traditional monoethanolamine (MEA) and methyldiethanolamine (MDEA) solvents into alternatives that have significantly reduced operating costs and improved environmental performance, even when utilizing conventional static packing bed operations.

In the ROTA-CAP project, the partners aim to create a prototype process plant that will deliver performance improvement that is dramatically greater. Indeed, the high gravity of the bed allows the team to consider advanced solvent chemistries that would be impossible to use with a static system. When relying primarily upon gravity, solvents must flow smoothly—in fact, solvents used in these systems must be diluted with upwards of 70-75%

water to optimize material flow, not only limiting performance but also adding cost to the system.

For the ROTA-CAP system, with the multiple g-force of the rotation forcing the liquid through the dense packing, CCSUS envisions an intensified solvent which is less constrained by viscosity limitations, that will absorb more CO2 per volume without the need for artificial solvent dilution or tall contacting columns.

Of note, the team's innovative design also utilizes a second integrated high gravity system to efficiently separate the solvent and captured CO2 into separate streams after absorption. The system is a closed continuous process, with regenerated solvent pumped back into the absorber for reuse, and the high purity CO2 ready for transfer to a utilization facility or appropriate sequestering process.

The ROTA-CAP process is utilizing technical innovation to develop a fully integrated, intensified CO2 capture process with the ultimate goal of achieving breakthrough CO2 capture economics.

Many areas of cost savings

As noted, the ROTA-CAP system has the potential to significantly reduce the CO2 capture cost from current levels of $50-$75 per tonne to the U.S. Department of Energy's target of $30 per tonne or less. Several efficiencies of the technology combine to provide this overall cost savings potential.

Perhaps the largest proportion of the cost reduction can be attributable to the substantial savings in amortized capital construction and infrastructure costs related to the building of huge industrial towers, which can demand upfront investment into the billions of dollars, as well as the related permitting, regulatory and legal expenses.

With the ROTA-CAP system reducing the size of the treatment area necessary by up to 90%, the system could theoretically be placed on existing facility rooftops or in adjacent spaces along with air conditioners and other HVAC equipment, minimizing the need for additional footprint, potentially, to zero.

Similarly, the reduced sizing requirement of internal equipment such as circulation pumps, piping, heaters and coolers—by up to 50% or more—will generate significant additional savings both upfront and in ongoing maintenance costs.

Further, it should be noted that a large part of the relatively high cost of many types of equipment in the hot sections of these towers stems from the demands of their high end metallurgy.

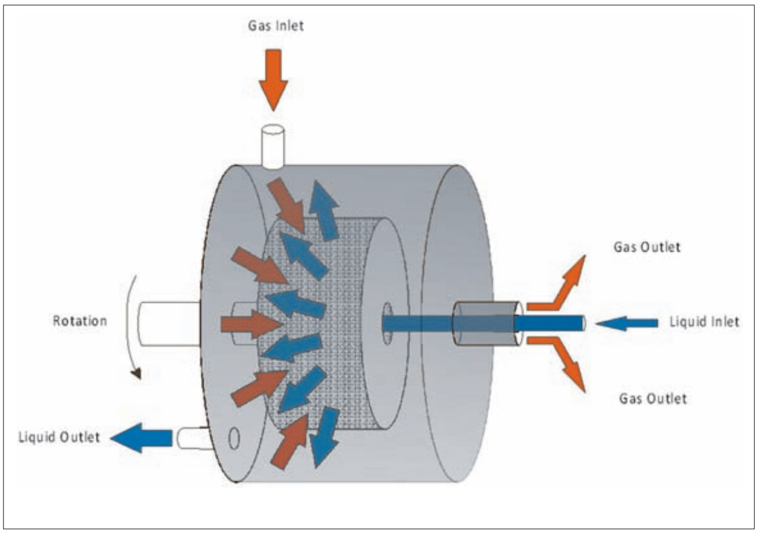
The threat of corrosion in conventional systems, with less effective solvents and greater heat demands, leads to the specification of more costly materials and engineering expertise. These demands—and subsequent costs—could be greatly relaxed in the ROTA-CAP system.

In addition, there is expected to be ongoing energy savings due to a number of factors that may offset the incremental power demands of bed rotation. The intensified solvent in ROTA-CAP offers very high CO2 loading capacity and fast CO2 absorption kinetics leading to significant energy savings (up to 45%) as compared to the incumbent MEA technology.

The compact modular CO2 capture system will offer significant reductions to the volume of solvent required for the process and therefore equivalent reductions in the corresponding energy demanded to circulate the solvent. It also leads to significantly less wear and tear on equipment, bolstering equipment life and further reducing maintenance and operating costs.

Wide spread applications

Although the DOE research grant is focused on the needs of coal fired power plants, the ROTA-CAP technology is flexible and will be readily applicable to any of the myriad applications that rely upon carbon capture. This includes natural gas and oil-fired power generation facilities, as well as a multitude of industrial processes that use heat or gas separations in their manufacturing processes, from cement production to chemical processing to oil refining and more.



The ROTA-CAP system developed by GTI and Carbon Clean Solutions USA uses a high speed rotating disc and a new advanced solvent that is being specifically developed for the process

In fact, any facility that needs to take CO2 out of their effluent—or, more broadly, any industrial operation that involves gas-liquid contact—could likely benefit from the ROTA-CAP system.

Further, with the potential scalability of the process, the ROTA-CAP system could deliver benefits to a variety of facilities from large megawatt power plants to modest-sized manufacturing facilities, especially when considering operating multiple ROTA-CAP systems as parallel trains.

In addition, the smaller footprint needed for carbon capture could also open the door to marine and offshore platform applications where space is at an even greater premium than land-based applications, and where movement would make the operation of conventional high-towered, gravity-based carbon capture systems wholly impractical.

With all of these cost, environmental and operational benefits, the ROTA-CAP technology has the potential to provide economical, efficient carbon capture capabilities far superior to current methodologies, enabling continuing use of fossil fuels to generate clean, low-cost electricity for generations to come.

More information

www.gti.energy
www.carboncleansolutions.com

Ten years of technology development at the National Carbon Capture Center

The National Carbon Capture Center, a U.S. Department of Energy (DOE)-sponsored research user facility managed and operated by Southern Company, has announced a significant milestone: 10 years of technology development.

The achievement represents more than 100,000 hours of neutral pilot testing to accelerate the development of technologies to reduce greenhouse gas emissions from fossil-fueled power plants.

Since its creation in 2009, the National Carbon Capture Center – with DOE's National Energy Technology Laboratory and other partners – has collaborated with third-party developers from the U.S. and six other countries. Located in Wilsonville, Alabama, adjacent to Southern Company subsidiary Alabama Power's Plant Gaston, the facility offers a pathway for carbon capture innovators from universities, industry and the government to move novel technologies out of the lab and into real-world operating conditions – a key step in future commercial deployment.

Through the testing of approximately 60 technologies, the National Carbon Capture Center has already participated in the reduction of carbon capture costs from fossil-fueled power generation by one-third. The center is currently adding infrastructure to broaden its testing of carbon capture technologies for natural gas power plants. This new capability is expected to further reduce carbon capture costs, enable flexible operation on both coal and natural gas and help identify options for the continued use of fossil energy as a U.S. power generation resource.

Reflecting its leadership in carbon capture technology innovation, the National Carbon Capture Center co-founded the International Test Center Network, a global carbon capture, utilization and storage (CCUS) technology coalition.

Achievements

The National Carbon Capture Center is currently focused on carbon capture technologies for natural gas and coal power plants; however, a significant amount of progress was made on gasification and pre-combustion carbon capture technologies tested at the center.

More than 30 post-combustion projects with the potential to substantially reduce carbon capture costs have been tested at the National Carbon Capture Center. The state-of-the-art facilities, offering technology developers realistic operating conditions and high-quality data acquisition, are routinely modified to expand testing opportunities. In addition to coal-derived flue gas, the center will soon be able to provide natural gas flue gas with various process conditions. Through testing at the site, several technologies have progressed through scale-ups as they move toward commercial deployment.

As part of its original mission—accelerating the commercialization of advanced technologies to enable fossil fuel-based power plants to achieve near-zero emissions—the National Carbon Capture Center evaluated gasification and precombustion carbon capture processes to support the development of next-generation power generation. More than 50,000 hours of technology testing was achieved utilizing syngas generated from the center's Transport Gasifier to evaluate low-carbon energy options and processes to improve the environmental and reliability aspects of gasification. In many cases, testing led to scale-ups and process intensification. These two areas of testing continued through 2017, when test priorities changed to focus more on post-combustion carbon capture for natural gas and coal power plants.

Current activities

Solvent-Based Carbon Capture Projects
While solvent-based carbon capture, particularly amine scrubbing, enjoys a high degree of technical readiness, the increase in cost of electricity (COE) using the industry-standard solvent monoethanolamine (MEA) could exceed 70 percent. A critical area of research for solvent-based carbon capture is the identification of advanced solvents with high capacity for carbon dioxide (CO2) loading and lower regeneration energy requirements than MEA. Next-generation solvents must also be low cost, non-corrosive, fast reacting and degradation-resistant.

Sorbent-Based Carbon Capture Projects
Unlike most solvents, CO2 solid sorbents contain no water and therefore offer much lower heating and regeneration energy requirements. To advance sorbents as a viable carbon capture solution, research and development is underway to demonstrate sorbents' low cost, thermal and chemical stability, resistance to attrition, low heat capacity, high CO2 loading capacity, and high selectivity for CO2. Optimization of process equipment designs is also needed to suit the characteristics of each type of sorbent.

Membrane-Based Carbon Capture Projects
Gas separation membranes offer several notable advantages for carbon capture applications: simple, modular designs; no need for steam or chemicals; and unit operation as opposed to complex processes. Membranes are being researched as a step-change improvement for carbon capture. Goals in this area are to develop membranes with low cost and durability, enhanced permeability and selectivity, thermal stability, and tolerance to flue gas contaminants.

More information

www.nationalcarboncapturecenter.com

U.S. 45Q tax credit could have major impact on CO2 emissions

The Clean Air Task Force study found that nearly 49 million metric tonnes of CO2 could be captured and stored annually by 2030 through CCS on U.S. coal- and gas-fired power plants.

CATF's modeling takes into account the passage and signing one year ago of the Bipartisan Budget Act that included the expansion and extension of the 45Q corporate income tax credits. These credits are expected to enable additional deployment of CCS projects in the U.S. and as a result will help reduce carbon emissions while meeting energy needs and supporting domestic jobs. The study covers the impact of 45Q on the power sector only, although 45Q tax credits will likely spur CCS projects on industrial facilities as well.

CATF retained Charles River Associates, a leading economic consulting firm that developed the North American Energy and Environment Model (NEEM), for the modeling underlying the report. NEEM is widely used by power utilities in the U.S for making strategic capacity and rate decisions.

"Our study projects that the CCS tax incentive could result in nearly 49 million metric tonnes of CO2 captured and stored annually by 2030 through CCS on U.S. coal- and gas-fired power plants. That amount of CO2 reduction is equivalent to taking seven million cars off the road, a number greater than the number of new cars sold in the US in 2017," said Deepika Nagabhushan, Energy Policy Associate for CATF and lead author of the study.

"Our study also projects that by 2030, 45Q could help the U.S. achieve more than two-thirds of the share of carbon capture that is needed on our power sector in order to limit global warming to 2-degrees, based on assessments by the International Energy Agency (IEA)" she said.

"So far, we've seen a few companies that have expressed strong interest in capitalizing on the tax breaks from 45Q," said Nagabhushan. "As a next step, the U.S. Treasury must issue updated guidance on the requirements for claiming 45Q tax credits. After that, we can expect carbon capture projects to ramp up in the near term towards the levels modeled in our study.

"However, to achieve much wider deployment of CCS in the longer term as seen in IEA's 2-degree modeling scenario, a suite of strategic policies would need to be implemented targeting all parts of the capture, transport and storage industries, and further extension of 45Q tax credits may be a part of that strategy."

Importantly, the modeling results show that the 45Q-induced power sector CO2 reductions are additive to those achieved through renewable sources of electricity generation.

The modeling results from the analysis also show that 45 units of coal and natural gas power plants could be retrofitted with CCS, resulting in a total of 10.8 GW of generating capacity with carbon controls. Currently one coal-fired power plant in Texas – Petra Nova – and one in Saskatchewan – Boundary Dam – are capturing CO2and sequestering it through EOR, so the prognosis for rapid expansion of the technology under 45Q is very encouraging.

The results indicated that CO2 is stored in oil fields within three regions. California would store 6.4 million tonnes per year, East & Central Texas 19 million tonnes and the Mid-Continent region 23.5 million tonnes. To assess the growth level projected by the modeling, the study compared the results to historic U.S. EOR regional growth rates, which ranged from 3.6 to 19 million tonnes per year. This suggests that the modeled regional growth rates are not out of line with previous growth periods. Furthermore, the largest rates of past growth were spurred by tax policy.

Conclusions

45Q has the potential to support deployment of CCS in the U.S. at levels that can remove approximately 49 million tonnes of CO2 emissions on a yearly basis by 2030 from the power sector alone.

Using IEA's well-to-wheels analysis of life cycle CO2 emissions from EOR, CATF's results would amount to almost 31 million tonnes of net CO2 emission reduction. Further, CATF's analysis of historic growth rates in the CO2-EOR industry in the western U.S. suggests that the infrastructure build out necessary to support the levels our modeling predicts can be achieved by 2030.

45Q offers the opportunity to achieve additional CO2 emission reductions complementary to reductions that would be achieved by renewable energy growth in the power sector. In this way, the incentive offers a near-term pathway to meeting IEA's 2030 target for CO2 reduction through CCS in the domestic power sector, an essential step towards achieving global climate goals.

However, to stay on track with meeting larger targets for 2050 and beyond, and attempting to not overshoot 1.5 degrees Celsius in global temperature rise, additional policy pathways – particularly at the state level – may need to be explored and analyzed.

More information

www.catf.us

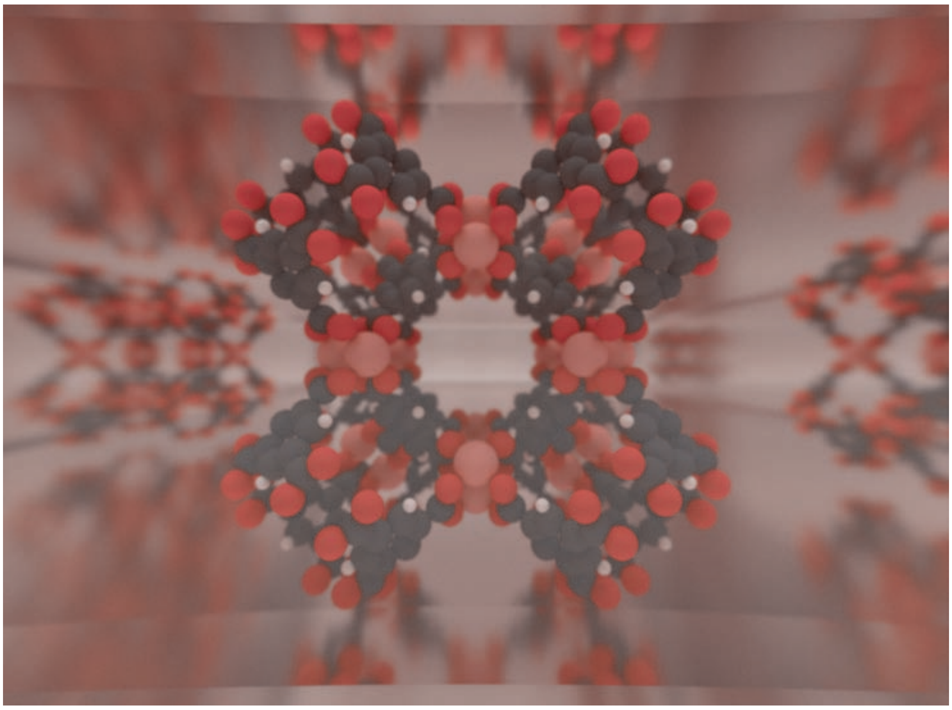
Membranes to capture CO2 at coal-fired power plants

A computational modelling method may help to fast-track the identification and design of new carbon capture and storage materials.

A computational modeling method developed at the University of Pittsburgh's Swanson School of Engineering may help to fast-track the identification and design of new carbon capture and storage materials for use by the nation's coal-fired power plants. The hypothetical mixed matrix membranes would provide a more economical solution than current methods, with a predicted cost of less than $50 per ton of carbon dioxide (CO2) removed.

The research group -- led by Christopher Wilmer, assistant professor of chemical and petroleum engineering, in collaboration with co-investigator Jan Steckel, research scientist at the U.S. Department of Energy's National Energy Technology Laboratory, and Pittsburgh-based AECOM -- published its findings in the Royal Society of Chemistry journal Energy & Environment Science.

"Polymer membranes have been used for decades to filter and purify materials, but are limited in their use for carbon capture and storage," noted Dr. Wilmer, who leads the Hypothetical Materials Lab at the Swanson School. "Mixed matrix membranes, which are polymeric membranes with small, inorganic particles dispersed in the material, show extreme promise because of their separation and permeability properties. However, the number of potential polymers and inorganic particles is significant, and so finding the best combination for carbon capture can be daunting."



Depiction of a metal-organic framework (HKUST-1) embedded in a polymer matrix to be used as a membrane for efficient gas separations. (Kutay Sezginel)

According to Dr. Wilmer, the researchers built upon their extensive research in metal-organic frameworks (MOFs), which are highly porous crystalline materials created via the self-assembly of inorganic metal with organic linkers. These MOFs, which can store a higher volume of gases than traditional tanks, are highly versatile and can be made from a variety of materials and custom designed with specific properties.

Dr. Wilmer and his group explored existing databases of hypothetical and real MOFs for their research, resulting in more than one million potential mixed matrix membranes. They then compared the predicted gas permeation of each material with published data, and evaluated them based on a three-stage capture process.

Variables such as flow rate, capture fraction, pressure and temperature conditions were optimized as a function of membrane properties with the goal of identifying specific mixed matrix membranes that would yield an affordable carbon capture cost. The potential implications for the Wilmer group's research are tremendous.

Although coal-generated power plants in the U.S. alone currently represent only 30 percent of nation's energy portfolio, in 2017 they contributed the largest share of 1,207 million metric tons of CO2, or 69 percent of the total U.S. energy-related CO2 emissions by the entire U.S. electric power sector. (Source: U.S. Energy Information Administration.)

"Our computational modeling of both hypothetical and real MOFs resulted in a new database of more than a million mixed matrix membranes with corresponding CO2 capture performance and associated costs," Dr. Wilmer said.

"Further techno-economic analyses yielded 1,153 mixed matrix membranes with a carbon capture cost of less than $50 per ton removed. Thus, the potential exists for creating an economically affordable and efficient means of CO2 capture at coal power plants throughout the world and effectively tackling a significant source of fossil fuel-generated carbon dioxide in the atmosphere."

More information

www.engineering.pitt.edu

U.S. CCUS news

DOE invests $24 Million to advance Carbon Capture technologies

www.netl.doe.gov

U.S. Secretary of Energy Rick Perry announced the selection of eight projects to receive nearly $24 million.

The selected projects will focus on the development of solvent, sorbent, and membrane technologies to address scientific challenges and knowledge gaps associated with reducing the cost of carbon capture. Secretary Perry announced these projects today at a joint press conference with International Energy Agency Executive Director, Dr. Fatih Birol.

"By 2040 the world will still rely on fossil fuels for 77% of its energy use. Our goal is to produce them in a cleaner way," said U.S. Secretary of Energy Rick Perry. "These projects will allow America, and the world for that matter, to use both coal and natural gas with near-zero emissions."

These carbon capture projects are funded by the Office of Fossil Energy's (FE's) Carbon Capture Program. The National Energy Technology Laboratory will manage the projects:

Advanced Structured Adsorbent Architectures for Transformative CO2 Capture Performance – Electricore, Inc. (Valencia, CA) intends to develop an optimized, commercially feasible carbon dioxide (CO2) capture technology architecture in collaboration with Inventys, DNV GL USA, and Susteon.

The process includes a dual-adsorbent bi-layer structured adsorbent design with a thermal conductive matrix that will enable a rapid temperature swing 40 to 100 times faster than a conventional thermal swing process. In-house bench-scale testing will be conducted on simulated flue gas and actual flue gas from a gas-fired boiler.

Transformational Sorbent-Based Process for a Substantial Reduction in the Cost of CO2 Capture – InnoSepra, Inc. (Middlesex, NJ) plans to demonstrate a carbon capture process that uses physical sorbents featuring low heats of sorption in collaboration with Arizona State University, Mainline Engineering, Process Plant Equipment, and the Technology Centre Mongstad (TCM).

This process will allow heat extraction to occur at lower temperatures than with solvent-based processes, which is expected to reduce capital costs and parasitic power loss. Testing will be conducted with actual flue gas at TCM.

Validation of Transformational CO2 Capture Solvent Technology with Revolutionary Stability – ION Engineering, LLC (Boulder, CO) intends to conduct a comprehensive bench-scale test campaign in collaboration with Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), Optimized Gas Treating, Sargent & Lundy, Hellman and Associates, and the National Carbon Capture Center (NCCC) to test their novel solvent.

The project aims to further understand the key performance indicators of their novel solvent technology and validate the solvent performance at 0.6 MWe. Testing will be conducted at the NCCC utilizing U.S. coal-fired flue gas and will also validate a unique process simulation model for plant design.

Novel Transformational Membranes and Process for CO2 Capture from Flue Gas – Ohio State University (Columbus, OH) plans to develop a cost-effective design and fabrication process for a spiral wound polymer membrane and its membrane modules that will demonstrate high reactivity with CO2, high CO2 permeance, and very high CO2/N2 selectivity.

Researchers will optimize and scale up the membrane to a prototype size via continuous roll-to-roll fabrication and construct and test a bench skid for testing the integrated membrane process. These membranes will first undergo parametric testing with simulated flue gas in the skid and then with actual flue gas at the NCCC.

Transformational Molecular Layer Deposition Tailor-Made Size-Sieving Sorbents for Post-Combustion CO2Capture – Rensselaer Polytechnic Institute (Troy, NY) intends to develop a transformational sorbent integrated with a tailored pressure swing adsorption cycle schedule in collaboration with the University of South Carolina (USC), Gas Technology Institute, Trimeric Corporation (Trimeric), and the NCCC.

This technology can be installed in new or retrofitted onto existing pulverized coal power plants at a lower cost for CO2 capture. Testing will first be conducted with simulated flue gas at USC and then tested with actual flue gas at the NCCC.

Rational Development of Novel Metal-Organic Polyhedra-Based Membranes for CO2 Capture – Research Foundation for SUNY on behalf of the University at Buffalo (Amherst, NY) plans to develop transformative mixed matrix membranes in collaboration with the California Institute of Technology, Membrane Technology and Research, Rensselaer Polytechnic Institute, Trimeric, and the NCCC.

The membranes will contain advanced materials, such as metal organic polyhedras and rubbery polymers, to achieve high CO2 permeance, high CO2/N2, and high CO2/O2 selectivity at temperatures up to 60 degrees Celsius. Testing will be conducted at the NCCC.

Novel Next Generation Sorbent System for Post-Combustion CO2 Capture – TDA Research, Inc. (Wheat Ridge, CO) intends to develop a transformational sorbent system for a post-combustion CO2 capture process in collaboration with the University of California at Irvine, the University of Alberta, and the Wyoming Integrated Test Center.

The technology features a high-capacity sorbent with a vacuum concentration swing adsorption process that enables use of a single-stage vacuum pump with a low auxiliary load. Testing will be conducted on actual flue gas at the Wyoming Integrated Test Center.

Fog + Froth-Based Post-Combustion CO2 Capture in Fossil-Fuel Power Plants – University of Kentucky Research Foundation (Lexington, KY) plans to fabricate, integrate and research a compact absorber with integrated fog and froth formation zones.

Testing will be conducted at the University of Kentucky's Center for Applied Energy Research bench post-combustion CO2 capture facilities using both simulated and real coal-derived flue gas.

DOE Issues Notice of Intent for Carbon Storage Funding

energy.gov

The U.S. Department of Energy (DOE) is-

sued a Notice of Intent (NOI) to provide federal funding for research and development (R&D) projects that contribute to the development of transformational sensing capabilities for monitoring parameters associated with subsurface carbon dioxide (CO2) storage.

The National Energy Technology Laboratory (NETL) will manage the projects selected under the Funding Opportunity Announcement (FOA), "Transformational Sensing Capabilities for Monitoring the Subsurface," which will be issued in fiscal year (FY) 2019. The objective of the FOA is to competitively solicit and award R&D projects that improve existing technologies to reduce uncertainty and enable realtime decision-making associated with subsurface CO2 storage.

California CCS Protocol takes effect under low carbon fuel standard

www.globalccsinstitute.com

The Global CCS Institute has welcomed California's Air Resources Board's (ARB) decision to include a protocol for carbon capture and storage (CCS) in its Low Carbon Fuel Standard (LCFS), a rule which became effective on January 1, 2019.

The protocol allows transportation fuels whose lifecycle emissions have been reduced through CCS to become eligible for credits under the LCFS.

"The inclusion of the CCS protocol in the LCFS signals that California – arguably one of the most active states when it comes to combatting climate change – recognizes that CCS has a role in its energy transition to deliver emissions reductions", says Guloren Turan, General Manager, Advocacy and Communications, at the Global CCS Institute.

Currently, the credits are trading at roughly $180 per ton, and can be combined with the federal tax credit for CCS projects. Also known as 45Q, the federal tax credit provides $50/t for CO2 stored geologically, and $35/t for CO2 stored permanently via enhanced oil recovery. "In the medium term, the establishment of a CCS protocol also paves the way for CCS to become eligible in the state's Cap-and-Trade Program", says Turan.

CARB's decision comes on the heels of two other landmark climate commitments in California, which the Global CCS Institute applauds. In September, the California State Legislature passed SB100, which requires the state to generate 100% of electricity from carbon-free sources with a renewable portfolio standard of 60% built in. The same month, former Governor Jerry Brown also signed Executive Order B-55-18, requiring the entire economy to achieve carbon neutrality by 2045.

Fault lines are no barrier to safe CO2 storage

www.ed.ac.uk/geosciences

Carbon dioxide emissions can be captured and securely stored in underground rocks, even if geological faults are present, research has confirmed.

There is minimal possibility of the gas escaping from fault lines back into the atmosphere, a study has shown.

The latest findings, from tests on a naturally occurring CO2 reservoir, may address public concerns over the proposed long-term storage of carbon dioxide in depleted gas and oil fields.

Scientists from the Universities of Edinburgh, Freiburg, Glasgow and Heidelberg studied a natural CO2 repository in Arizona, US, where gas migrates through geological faults to the surface.

Researchers used chemical analysis to calculate the amount of gas that had escaped the underground store over almost half a million years.

They found that a very small amount of carbon dioxide escaped the site each year, well within the safe levels needed for effective storage.

The study, published in Scientific Reports, was supported by the European Union and Natural Environment Research Council.

"This shows that even sites with geological faults are robust, effective stores for CO2," said Dr Stuart Gilfillan, School of GeoSciences, University of Edinburgh. "This find significantly increases the number of sites around the world that may be suited to storage of this harmful greenhouse gas."

UK's Acorn project now ready for FEED

Having completed a round of initial study, the UK's "Acorn" carbon capture and storage project, based at St Fergus, North of Peterhead, is now ready for FEED.
By Karl Jeffery

The UK's Acorn carbon capture project, based in North East Scotland, is now ready for Front End Engineering and Design (FEED).

The project team hope to get a final investment decision on the project by the end of 2020 (which would require the front-end engineering and design to be completed and assessed). This could enable the first well to be drilled in 2022, the project operational by 2023, and hydrogen production starting in 2024.

Project developer Pale Blu Dot Energy is leading the project, with support from Total.

The ACT study phase had close support was funded by the EU's Accelerating CCS Technologies programme, with close support from Bellona, as a "research partner", and "academic partners" including Heriot-Watt University, Scottish Carbon Capture and Storage (SCCS), University of Aberdeen, University of Edinburgh, University of Liverpool and Radboud University.

Sam Gomersall, commercial director of Pale Blue Dot, says that his company is "currently finalising funding for FEED with public and industry funding agreed in principle".

Pale Blue Dot is discussing funding for the projects construction with "various organisations," , but is always keen to meet new potential funders, who have a strategic interest in carbon capture and storage and who recognise that CCS is not yet a commercial / mature market, he says.

The project aims to initially sequester 200,000 tonnes CO2 per year, which should be "enough to get open for business", says Alan James, managing director of Pale Blue Dot.

The sequestration rate could be expanded by bringing in CO2 delivered by ship via a deepwater port in Peterhead, which is a few miles from the St Fergus gas terminal. It could handle 6m tonnes a year, in "3 or 4 ships". This would be mean capturing emissions from multiple industrial facilities, perhaps including CO2 from industrial plants at Teesside, 300 miles down the coast.

CO2 could be delivered via the "Feeder 10" gas pipeline running from Grangemouth to St Fergus, a natural gas pipeline which has the potential for re-use. This pipeline is currently owned and operated by National Grid, as part of the UK's gas pipeline infrastructure. The pipeline could be sold to a CO2 transport company, or National Grid could retain ownership.

The project team is planning for a "reference case" of 200,000 tonnes from one facility, the offshore pipeline has a capacity of 5MT/y providing considerable potential for low cost build out, through Feeder 10 or with CO2 arriving by ship.

Note information about ACT ACORN is available online at https://www.actacorn.eu and about the main Acorn CCS Project on the Pale Blue Dot website https://paleblu.com/

Lowest cost

The capital needed for this is estimated at £276m, not including the cost of the steam methane reforming plant, but covering the CO2 compression, wells and control systems.

The Acorn project was designed to be the lowest possible cost route to getting started with carbon capture.

Many people have commented on the "chicken and egg" problem with carbon capture and storage – no-one wants to build storage without any CO2, and no-one wants to capture CO2 without any storage. The Acorn project aims to get around this by building a full chain project to initiate CCS

Rather than build a new coal or gas power station, or retrofit carbon capture to an existing power station, the project aims to get a supply of CO2 in the cheapest possible way – and this was thought to be by building a steam methane reforming (SMR) plant to convert methane to hydrogen and CO2, with hydrogen added directly into the gas grid.

The SMR plant would be built at St Fergus, North East Scotland, at the point a large gas pipeline comes ashore, carrying 35 per cent of the UK's entire natural gas production. St Fergus already has pipeline access to well understood offshore storage, and the pipeline has some re-use life.

The regulations for the UK's gas grid today do not allow hydrogen, but there is lots of work going on to try to change this, Mr Gomersall says.

A report by the Institution of Gas Engineers and Managers (IGEM) states "It is thought that hydrogen could be mixed or blended in with natural gas, possibly up to around 20%(volumetrically), equivalent to about 6% on an energy basis, and be safely used in most existing gas appliances".

The plan would not call for any new offshore infrastructure apart from one well, because this would add to the cost of the project. The CO2 can be compressed on shore and then delivered directly into the storage sites via the existing pipeline and new well.

Steam methane reforming

The cost of building a steam methane reforming (SMR) plant has been estimated on similar projects at around £200m, a large sum but much less than the cost of building a new coal plant or carbon capture plant on an existing coal power station.

Steam methane reforming means reacting natural gas with water to form hydrogen and carbon monoxide, with carbon monoxide subsequently reacted with water to form more hydrogen and carbon dioxide.

Separating CO2 from hydrogen is much simpler than separating CO_2 from air (as in a conventional power station flue gas carbon capture plant), and so the cost of the carbon "capture" plant is much less.

Pipelines

The project team have thought carefully about the choice of pipelines they would like to use, choosing pipelines which should be available for CO_2, which have adequate remaining operational life, and are close to known CO_2 storage resources.

Three pipelines are being considered. The Atlantic pipeline, which is 78km long, 406mm diameter, and has a £102m replacement cost. It was built in 2006, operated for just 4 years, and has 20 year design life.

The Goldeneye pipeline, which is 508mm diameter and 102km long, has a £132m replacement cost. It has a 20 year design life and was operated for 8 years, from 2004 to 2011.

And the Miller gas pipeline, which is 762mm diameter, and 240km long, and has a £314m replacement cost. It has a 20 year design life and was operated for 16 years from 1992 to 2007.

With pipelines not being used, the operators and authorities are making decisions about whether to leave the pipelines in place (but suspended), or decommission them. It is important that people involved in decommissioning decisions are aware of the potential use for CO_2 sequestration, even if it takes a few years to get the CO_2 project running.

Storage

A comprehensive review of storage sites was conducted, ranking 16 different sites, picking the top 6, and choosing one preferred site out of these, plus a back-up.

The preferred site would need £177m of capital spent offshore, including drilling a "dual completion" well, which can accept CO_2 at a wide range of flowrates.

The back-up option would require £372m of capital, because the storage site is further away. This site could also be brought onstream once the first site is full.

A back-up site is useful for the small likelihood that the first storage site does not perform as expected, since it is ultimately not possible to be completely sure a storage site will perform as expected until you try it. The Equinor Sleipner CO_2 storage project also had a similar set up with multiple back up sites, said Stuart Haszeldine, Professor of Carbon Capture and Storage at University of Edinburgh.

No killer blow

Speaking at a London event on Jan 23rd to announce the end of the research, Chris Stark, chief executive of the UK government's Committee on Climate Change (CCC), said that carbon capture and storage is still looking for a "killer blow" which would get policy makers to support it. "I think there's a problem in the way we tell the story. It is not lack of evidence it is something emotional," he said.

"At CCC we like CCS, it gives you options, and it makes it much cheaper to do this [fix the climate]. CCS is a genuinely strategic option – and keeps different pathways on the table. We need to land that killer blow."

ACT scheme

The research work into Acorn was funded by the "ACT" (Accelerating CCS Technologies") scheme, which is funded by nine national governments in the EU.

The first round of ACT had 10 funders from 9 countries, all European, with 11 projects submitted and 5 funded, to a total of Eur 41m.

The second ACT call, in 2018, with up to Eur 30m, had 22 projects funded. It had no European Commission funding, but was backed by countries directly, with France, Germany, Greece, Netherlands, Norway, Romania, Spain, Switzerland, Turkey, the US and UK being the current backers.

The ACT team are very keen to broaden the number of countries involved, with Canada, Japan, Australia, Mexico, Saudi Arabia, being encouraged to join the third round.

Views of oil and gas sector

Carbon Capture Journal had an opportunity to ask people from the UK's oil and gas industry what they thought of Acorn at a conference in Aberdeen on Feb 7 2019, "revitalising the UK Continental Shelf," organised by the UK's Oil and Gas Authority, Subsea UK, the Oil & Gas Technology Centre (OGTC) and the National Subsea Research Initiative (NSRI).

Professor Alexander Kemp, Professor of Petroleum Economics, University of Aberdeen, said that he thought the Acorn project was a good but tiny start, in terms of making a big overall impact on CO_2. But building it would have a useful "learning by doing" aspect, he said.

On this basis, it is disappointing that the previous UK carbon capture projects were shelved (such as White Rose and Peterhead), since there could have been a lot of "learning by doing", he said.

Professor Kemp said that his team has examined CO_2 enhanced oil recovery, but found it would be "quite difficult from an economic point of view".

He thought there might be more opportunity for carbon capture in the North Sea if it was just based on "straightforward storage," with emphasis on technology for CO_2 capture.

Carlo Procaccini, head of technology, Oil and Gas Authority (OGA) said that CCS is something which both operators and government are looking at. Within OGA is it being approached as a "long term opportunity to repurpose assets", as part of what OGA calls "energy transition".

On similar lines, OGA is also looking at "gas to wire", where gas is combusted to generate electricity offshore, just bringing the electricity to shore, and sequestering the CO_2 from the gas combustion offshore.

But overall for North Sea carbon capture, "in practical terms, there are vital steps to assess economically and strategically," he said.

More information

www.actacorn.eu

www.pale-blu.com/acorn

www.total.com

www.sccs.org.uk

Projects and policy news

Drax BECCS pilot project underway

www.drax.com

The first BECCS pilot project of its kind in the world at Drax Power Station in the UK has started capturing carbon dioxide.

The demonstration plant at the power station, near Selby in North Yorkshire, is using innovative technology, developed by Leeds-based C-Capture, to capture a tonne of CO2 a day, during the pilot.

It is the first-time carbon dioxide has been captured from the combustion of a 100% biomass feedstock anywhere in the world.

If the BECCS pilot can be scaled up to deliver negative emissions, Drax Power Station would be helping to remove the gases that cause global warning from the atmosphere at the same time as electricity is produced.

Engineers began commissioning the pilot plant in November with the first carbon now being captured, proving that the proprietary solvent developed by C-Capture can be used to isolate the carbon dioxide from the flue gases released when biomass is used to generate electricity.

Data being obtained about the CO2 capture process will continue to be analysed throughout the pilot to fully understand the potential of the technology and how it could be scaled up at Drax. Part of this will include identifying and developing ways to store and use the carbon dioxide being captured.

Drax has invested £400,000 in the pilot, which could be the first of several projects undertaken at the power station to deliver a rapid, lower cost demonstration of BECCS.

Study says hydrogen essential for Europe's energy transition

www.fch.europa.eu

Developed with input from 17 leading European industrial actors, the study lays out a pathway for the large-scale deployment of hydrogen and fuel cells until 2050 and quantifies the associated socio-economic impacts.

Hydrogen is an essential element in the energy transition and can account for 24% of final energy demand and 5.4m jobs by 2050, says the new study by the FCH JU, “Hydrogen Roadmap Europe: A sustainable pathway for the European Energy Transition“.

The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) is a unique public private partnership supporting research, technological development and demonstration (RTD) activities in fuel cell and hydrogen energy technologies in Europe. Its aim is to accelerate the market introduction of these technologies, realising their potential as an instrument in achieving a carbon-clean energy system.

The report makes the case that hydrogen is required to address the challenges ahead. At scale decarbonisation of key segments such as the gas grid, transport (particularly as relates to heavy duty vehicles), industrial processes that use high-grade heat and hydrogen as chemical feedstock require the use of hydrogen in large quantities.

In addition, the electrification of the economy and the large scale integration of intermittent renewable energy sources require large scale energy storage, enabling seasonal storage and the efficient transport of clean energy across regions at low cost. Hydrogen is the only at scale technology capable of addressing all of these challenges.

EU invests over €10bn in innovative clean technologies

ec.europa.eu

EU launches an investment programme worth over €10 billion for low-carbon technologies in several sectors to boost their global competitiveness.

The Commission wants to ensure that Europe continues to be at the top of the league as regards new high-value patents for clean energy technologies. This leadership provides a global competitive advantage, allowing Europe to harvest first mover benefits by increasing exports of European sustainable products and sustainable technology and business models.

On 28 November 2018, the European Commission adopted a strategic long-term vision for a prosperous, modern, competitive and climate neutral economy by 2050 – A Clean Planet for all. The strategy shows how Europe can lead the way to climate neutrality while preserving the competitiveness of its industries by investing into realistic technological solutions. This transition also requires further scaling-up of technological innovations in energy, buildings, transport, industry and agriculture sectors.

Commissioner for Climate Action and Energy Miguel Arias Cañete said: “Less than three months after adopting our strategic vision for a climate neutral Europe by 2050, we are putting the money where the mouth is. Our objective is to keep building a modern, competitive and socially fair Paris-aligned economy for all Europeans. For this to happen, we will need deployment of clean innovative technologies on an industrial scale.”

“This is why we are investing in bringing to the market highly innovative technologies in energy intensive industries, in carbon capture, storage and use, in the renewable energy sector and in energy storage. We are today unleashing technological solutions in all Member States and pressing the fast-forward button in our transition to a modern and climate-neutral society in Europe.”

The Commission aims to launch the first call for proposals under the Innovation Fund already in 2020, followed by regular calls until 2030.

The Innovation Fund will pool together resources amounting to around €10 billion, depending on the carbon price. At least 450 million allowances from the EU Emissions Trading System (EU ETS) Directive will be sold on the carbon market in the period 2020-2030. The revenues of these sales depend on the carbon price, which is currently around EUR 20.

Any undisbursed revenues from the Innovation Fund's predecessor, the NER 300 programme, will also be added to the Innovation Fund. Thus, the total endowment of the Fund can be around EUR 10 Billion.

The Innovation Fund aims to create the right financial incentives for companies and public authorities to invest now in the next generation of low-carbon technologies and to give EU companies a first-mover advantage to become global technology leaders.

Melbourne University scientists turn carbon dioxide back into coal

The research team led by RMIT University in Melbourne, Australia, have developed a new technique that can efficiently convert CO2 from a gas into solid particles of carbon.

Published in the journal Nature Communications, the research offers an alternative pathway for safely and permanently removing the greenhouse gas from our atmosphere.

Current technologies for carbon capture and storage focus on compressing CO2 into a liquid form, transporting it to a suitable site and injecting it underground.

But implementation has been hampered by engineering challenges, issues around economic viability and environmental concerns about possible leaks from the storage sites.

RMIT researcher Dr Torben Daeneke said converting CO2 into a solid could be a more sustainable approach.

"While we can't literally turn back time, turning carbon dioxide back into coal and burying it back in the ground is a bit like rewinding the emissions clock," Daeneke, an Australian Research Council DECRA Fellow, said.

Australian Research Council DECRA Fellow Dr Torben Daeneke and Vice-Chancellor's Research Fellow Dr Dorna Esrafilzadeh.

"To date, CO2 has only been converted into a solid at extremely high temperatures, making it industrially unviable. By using liquid metals as a catalyst, we've shown it's possible to turn the gas back into carbon at room temperature, in a process that's efficient and scalable. While more research needs to be done, it's a crucial first step to delivering solid storage of carbon."

How the carbon conversion works

Lead author, Dr Dorna Esrafilzadeh, a Vice-Chancellor's Research Fellow in RMIT's School of Engineering, developed the electrochemical technique to capture and convert atmospheric CO2 to storable solid carbon.

To convert CO2, the researchers designed a liquid metal catalyst with specific surface properties that made it extremely efficient at conducting electricity while chemically activating the surface.

The carbon dioxide is dissolved in a beaker filled with an electrolyte liquid and a small amount of the liquid metal, which is then charged with an electrical current.

The CO2 slowly converts into solid flakes of carbon, which are naturally detached from the liquid metal surface, allowing the continuous production of carbonaceous solid. Esrafilzadeh said the carbon produced could also be used as an electrode.

"A side benefit of the process is that the carbon can hold electrical charge, becoming a supercapacitor, so it could potentially be used as a component in future vehicles. The process also produces synthetic fuel as a by-product, which could also have industrial applications."

The research was conducted at RMIT's MicroNano Research Facility and the RMIT Microscopy and Microanalysis Facility, with lead investigator, Honorary RMIT and ARC Laureate Fellow, Professor Kourosh Kalantar-Zadeh (now UNSW).

The research is supported by the Australian Research Council Centre for Future Low-Energy Electronics Technologies (FLEET) and the ARC Centre of Excellence for Electromaterials Science (ACES).

The collaboration involved researchers from Germany (University of Munster), China (Nanjing University of Aeronautics and Astronautics), the US (North Carolina State University) and Australia (UNSW, University of Wollongong, Monash University, QUT).

The paper is published in Nature Communications ("Room temperature CO2 reduction to solid carbon species on liquid metals featuring atomically thin ceria interfaces", DOI: 10.1038/s41467-019-08824-8).

More information

www.rmit.edu.au

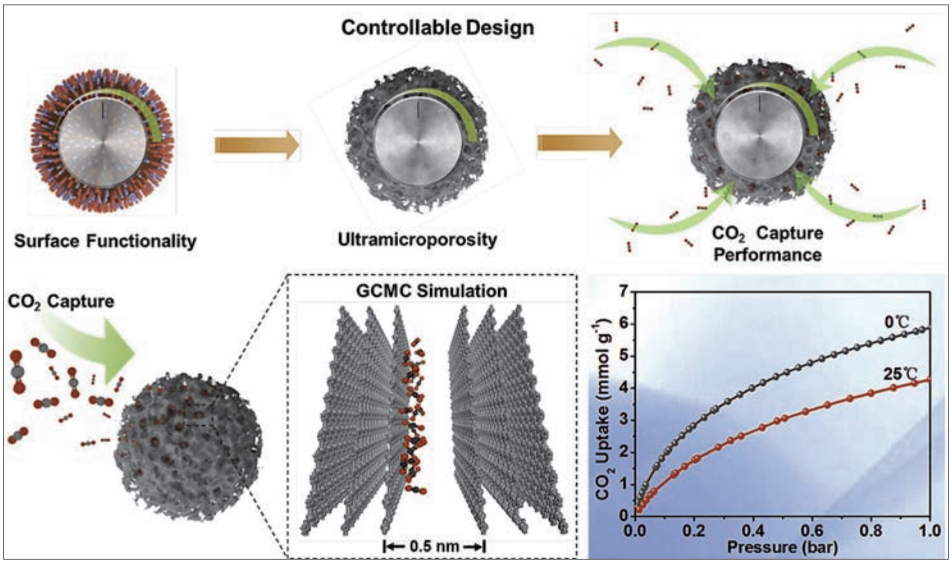
New powder could help cut CO2 emissions

Scientists at the University of Waterloo have created a powder that could capture carbon dioxide (CO2) from factories and power plants.

The carbon powder, developed using a novel process in the lab of Zhongwei Chen, a chemical engineering professor at Waterloo, could filter and remove CO2 from emissions at facilities powered by fossil fuels before it is released into the atmosphere with twice the efficiency of conventional materials.

"This will be more and more important in the future," Chen said. "We have to find ways to deal with all the CO2 produced by burning fossil fuels."

The new process, which involves manipulating the size and concentration of pores, could also be used to produce optimized carbon powders for applications including water filtration and energy storage, the other main strand of research in Chen's lab.



Carbon powders could be used to capture carbon

CO2 molecules stick to the surface of carbon when they come in contact with it, a process known as adsorption. Since it is abundant, inexpensive and environmentally friendly, that makes carbon an excellent material to capture CO2, a greenhouse gas that is the primary contributor to global warming.

The researchers, who collaborated with colleagues at several universities in China, set out to improve adsorption performance by manipulating the size and concentration of pores in carbon materials.

The technique they developed uses heat and salt to extract a black carbon powder from plant matter. Carbon spheres that make up the powder have many, many pores and the vast majority of them are less than one-millionth of a metre in diameter.

"The porosity of this material is extremely high," said Chen, who holds a Tier 1 Canada Research Chair in advanced materials for clean energy. "And because of their size, these pores can capture CO2 very efficiently. The performance is almost doubled."

Once saturated with carbon dioxide at large point sources such as fossil fuel power plants, the powder would be transported to storage sites and buried in underground geological formations to prevent CO2 release into the atmosphere.

A paper on the CO2 capture work, In-situ ion-activated carbon nanospheres with tunable ultramicroporosity for superior CO2 capture, appears in the journal Carbon.

More information

uwaterloo.ca

"Flipped" Metal Oxide Cage can sort CO2 from CO

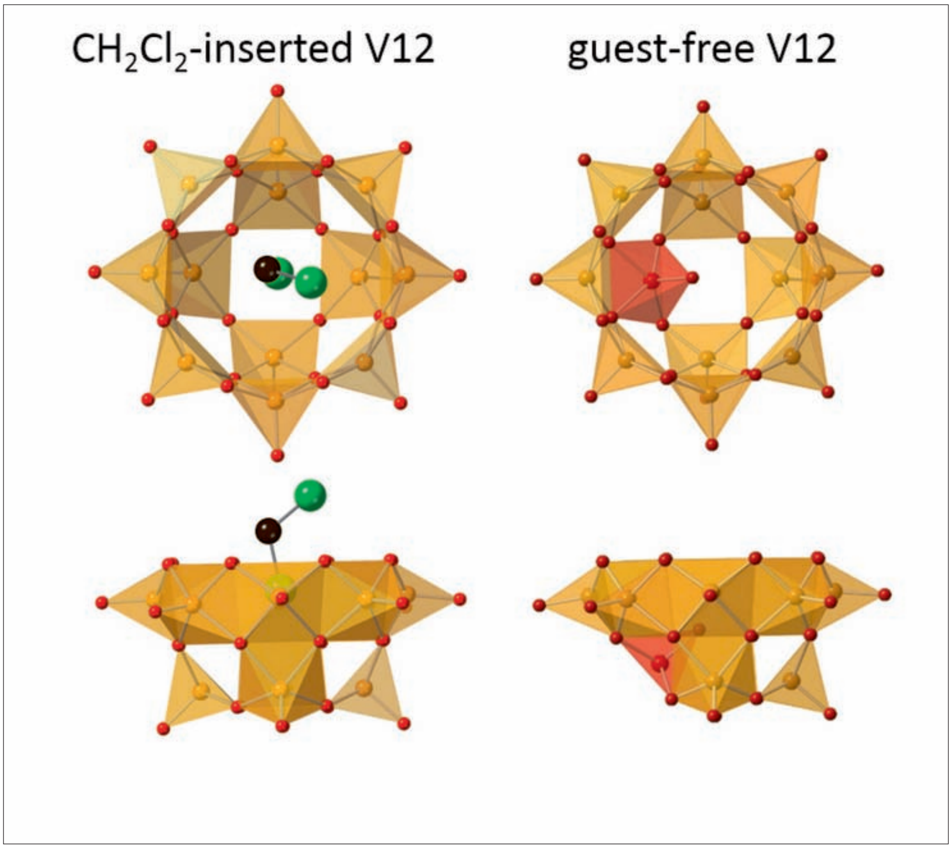
A Japanese research team led by Kanazawa University studied using a bowl of Vanadium to separate carbon dioxide from carbon monoxide.

A hollow, spherical cluster of vanadate molecules can discriminate between CO and CO2, allowing potential uses in CO2 storage and capture.

At the molecular scale, small objects can fit inside larger ones, just like in the everyday world. The resulting arrangements, known as host–guest interactions, are stabilized by non-covalent forces like electrostatics and hydrogen bonds. Each host will happily take in certain molecules, while shutting out others, depending on the size of its entrance and how much interior space it can offer the guest.

One such host is V12 – a rough sphere made from 12 atoms of the transition metal vanadium, connected through 32 oxygen atoms. The bowl-like structure has an opening at one end, with a width of 0.44 nanometers, perfect for letting in the right molecule to nestle inside the cavity.

"V12 accepts a range of guests on the scale of small organic compounds," says Yuji Kikukawa, co-corresponding author of the Kanazawa study in Angewandte Chemie. "In fact, it's rather hard to isolate an empty V12 by itself. While the host stabilizes its guest, so the guest returns the favor – if we remove the guest, the host quickly replaces it with another molecule."



Anion structures of CH2Cl2(guest)-inserted V12 (left) and guest-free V12 are shown. Orange and red square pyramids represent VO5 units with their bases directed to the center of the bowl, and the inverted VO5 unit. Green and black spheres represent Cl and C, respectively. Hydrogen atoms of CH2Cl2 are omitted for clarity

Each vanadium atom in V12 forms a square-pyramid with five oxygens. The oxygens of each VO5 point outwards, while the positive charge from vanadium fills the inner cavity, helping to stabilize electron-rich (or anionic) guests. However, the Kanazawa team created a guest-free V12 for the first time, by using a solvent—acetone—whose molecules are too bulky to fit through the entrance.

To make up for the missing guest, the empty V12 bowl did something unexpected. The VO5 unit at the bottom flipped inwards, like an umbrella inverting in heavy wind. Now, the host cavity was filled by the negative terminal oxygen of the single "upside-down" VO5.

This atomic shifting to accommodate a new structure, termed a polytopal rearrangement, had never been seen in metal oxide clusters. The structure transformation could be monitored by infrared spectroscopy.

"We then took the empty V12 and explored which guests we could insert back into the bowl," says the authors. "Nitrogen, methane and carbon monoxide were all rejected, but carbon dioxide was readily taken up. This immediately suggests a way to separate CO2 from other gases."

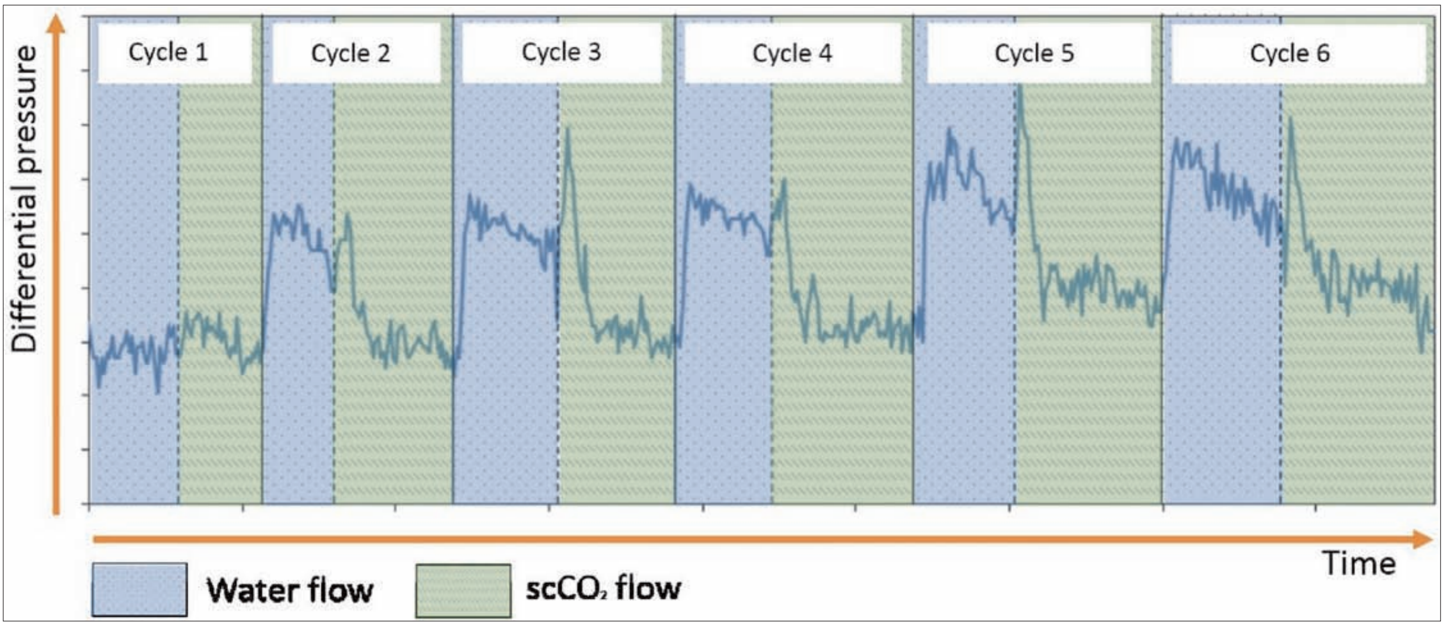
In fact, V12 and CO2 proved such a perfect fit that CO2 could be inserted even at low atmospheric pressure. V12 might therefore be an ideal solution in CO2 capture to combat climate change, and even in CO2 storage for the emerging technology of artificial photosynthesis.

More information

www.kanazawa-u.ac.jp

Varied CO2 injection rates can boost CO2 storage effectiveness

Varying the rate at which carbon dioxide is injected into geological storage sites can enhance not just their efficiency but also their ability to store the greenhouse gas securely, according to a new study from the University of Edinburgh.



Differential pressure results during cyclic flow for the Fell Sandstone sample. The cycle number is indicated at the top of the graph. The relevant fluid flow within each cycle is indicated in the key

These findings will be invaluable to developers of carbon capture and storage (CCS) projects in the UK and abroad, where varying injection rates and interruptions are expected to occur over a project's lifespan due to, for example, CO2 delivery rates from capture sites, pressure management and well maintenance.

The study by scientists at the University of Edinburgh suggests that, with every change or interruption to CO2 injection into a geological storage site:

• storage security would be enhanced because interruptions have the effect of increasing the amount of CO2 trapped within the pore spaces of the rock;

• the efficiency of storage is increased because trapped CO2 is less mobile than free flowing CO2 and so its migration within the reservoir is more contained;

• injection pressure would rise due to the increasingly trapped CO2 acting as a barrier to flow and this effect would need to be managed by storage site operators.

The researchers used rock samples to simulate the injection of CO2 and water into geological stores, creating numerical models which were then compared to a real-life, small-scale injection project at Otway in Australia.

As a CCS industry in the UK moves closer to reality, studies such as these illustrate just how the technology will work in practice and provide important data to guide development.

The paper Cyclic CO2 – H2O injection and residual trapping: Implications for CO2 injection efficiency and storage security by Katriona Edlmann, Sofi Hinchliffe, Niklas Heinemann, Gareth Johnson and Chris McDermott from the University of Edinburgh and Jonathan Ennis-King from CSIRO, Otway is published in the International Journal of Greenhouse Gas Control, January 2019.

The University of Edinburgh is one of the founding partners of the Scottish Carbon Capture & Storage (SCCS) research partnership.

More information

www.sccs.org.uk

Transport and storage news

Swansea plans large scale carbon sequestration field trials in US shale basins

www.swansea.ac.uk

Swansea University's Energy Safety Research Institute (ESRI) reveals plans for testing new technology to capture CO2 in full scale field trials.

Swansea University is part of a UK environmental coalition which is to pursue very large-scale decarbonization technology field trials spearheading construction of regional permanent carbon storage facilities in US shale basins.

Recently UK Energy and Clean Growth Minister Claire Perry announced the UK's goal to lead an international challenge to remove carbon from emissions. Consistent with this objective and highlighting the important role of innovation in supporting cost reduction, Very Large Scale Decarbonization Partners (VLS Decarb) announced its intention to carry out field trials of its profoundly large-scale capable CO2 sequestration system in several UK and EU locations.

Now VLS Decarb is planning similar field trials in several US shale basins where, pending results, these trial sites will be further developed into fully functioning carbon dioxide storage facilities capable of permanently storing a significant percentage of annual U.S. CO2 emissions. Initially targeted US shale basins include the Marcellus, Haynesville, and Eagle Ford.

VLS Decarb is in the process of securing Precedent Agreements for long-term carbon storage contracts from industrial, institutional and governmental clients seeking to mitigate CO2 emissions associated with their operations, and in some instances availing themselves of available US carbon tax credits (26 U.S. Code § 45Q - Credit for Carbon Dioxide Sequestration).

The company's major-market patented and globally patent pending suite of technologies hold the potential to permanently sequester atmospheric CO2 at the levels stipulated by the Paris Climate Change Accord of December 2015. Specifically, it could remove volumes of CO2 sufficient to arrest the progression of climate change and potentially reverse harmful effects being experienced from unmitigated CO2 emissions of human origins.

During the past five years, the technology has been advanced by an extensive R&D collaboration involving VLS Decarb's academic and industry partners, the Energy Safety Research Institute (ESRI) at Swansea University and an international array of academic and governmental institutions and funding agencies. This research and development partnership, funded by Innovate UK, has led to the development of novel materials that are key to enabling the Carbon Capture and Storage (CCS) concept.

In addition to an industry partnership with Glass Technology Services (GTS), ESRI brings a significant ongoing collaboration with University of Chester and Université Grenoble Alpes. The enabling research for this project has been supported by Innovate UK, and both the RICE and FLEXIS projects, which are part-funded by the European Regional Development Fund (ERDF) through the Welsh Government.

In the field so far, specifically focused and scoped tests have been undertaken which have demonstrated the viability of various key components of the system. The complete process will be tested in field trials going forward and the results are expected to demonstrate the widespread applicability of the technology and its commercial viability and self-sustaining features, such as supporting intermittent supplies of electric power generation (wind, wave and sun) while also providing the electric power required to drive the sequestration process itself.

The CO2 storage and power generation potentials are: approximately 35 years of global electric power requirements net of the energy consumed in sequestering all global CO2 emissions from all sources during the same time interval is provided by VLS Decarb alone. If wind, wave and solar, along with similar cohorts of clean (carbon neutral) energy sources could provide 50% of needs during the time we are sequestering, the result would obviously be approximately 70 years of carbon free electricity worldwide, with zero net CO2 emissions from all sources.

How it works

Research data demonstrates that the best use of unconventional (shale) reservoirs is to store CO2, the noxious byproduct of burning natural gas and other fossil fuels. Shale formations, which are ubiquitous in the Earth's crust, can potentially be harnessed to permanently store injected CO2 for time intervals measured in geologic terms, literally hundreds of millions of years. The following image illustrates the process, which occurs in eight basic steps:

The carbon sequestration process

Steps 1, 2 & 3 – Temporarily accessing planetary shale source rocks with a completely non-toxic production system and removing the natural gas (methane) within them.

Steps 4 & 5 – Massive surplus electric power production (net of the carbon capture and sequestration operations) while simultaneously achieving an extraordinary negative carbon footprint and the production of large volumes of fresh water.

Step 6, 7 & 8 – Refilling the emptied reservoir spaces with many times more volumes of atmospheric carbon dioxide than generated from the extracted methane, and then terminating the access pathways from these containers via natural bio-degradable means resulting in permanent large-scale CO2 sequestration throughout geologic time which is not dependent upon vertical well bore durability.

ESRI Founder and Director Professor Andrew R Barron said, “Traditional carbon sequestration is fraught with issues, in particular the economic incentive for industry to decarbonize itself. Our approach offers a significant opportunity for Industry and Governments to ensure a low carbon future while sustaining employment and the economy.”

VLS Decarb Founder John Francis Thrash MD said, "Carbon sequestration in source rock deposits is a universally available solution for permanently removing carbon from the environment that has been sitting plainly before our eyes and yet un-noticed until now. Ironically, the methane extraction allows for disposal of the necessary volume of CO2 required to reverse climate change. All of this is accomplished in one sustainable, commercially viable operation."

CCT 2019 HOUSTON
TEXAS, USA 3-7 JUNE

The IEA Clean Coal Centre's 9th International
Conference on Clean Coal Technologies

CCT 2019 comes to the USA for the first time on 3-7 June, 2019. The city of Houston plays host to this leading forum for innovation in the coal industry, giving delegates the opportunity to visit the **Petra Nova** project – the world's largest CCS facility on coal power, and **NET Power's** pioneering demonstration of the 'Allam Cycle' capture process.

Featuring three days of technical sessions, panel discussion and keynotes from leading figures in the industry, CCT 2019 will cover the research, demonstration and deployment of cleaner coal technologies and next-generation carbon capture systems.

Speakers include:

US Department of Energy	International CCS Knowledge Centre
China Energy	Mitsubishi Hitachi Power Systems
NTPC India	Mitsubishi HI
NRG	Gas Technology Institute
8 Rivers Capital	IHI Corporation
Southern Company	Inventys
Shanghai Shenergy Power Technology	ION Engineering
Peabody	CSIRO
European Commission	NICE America
Korea Institute of Energy Research	Bechtel
IEA Greenhouse Gas R&D Programme	SolarClean Fuels
Sam Tambani Research Institute	Tata Consultancy
The Institute of Clean Air Companies	Air Liquide
Euracoal	And many more

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www.cct-conferences.org