Carbon Capture Journal

CCS in the U.S.

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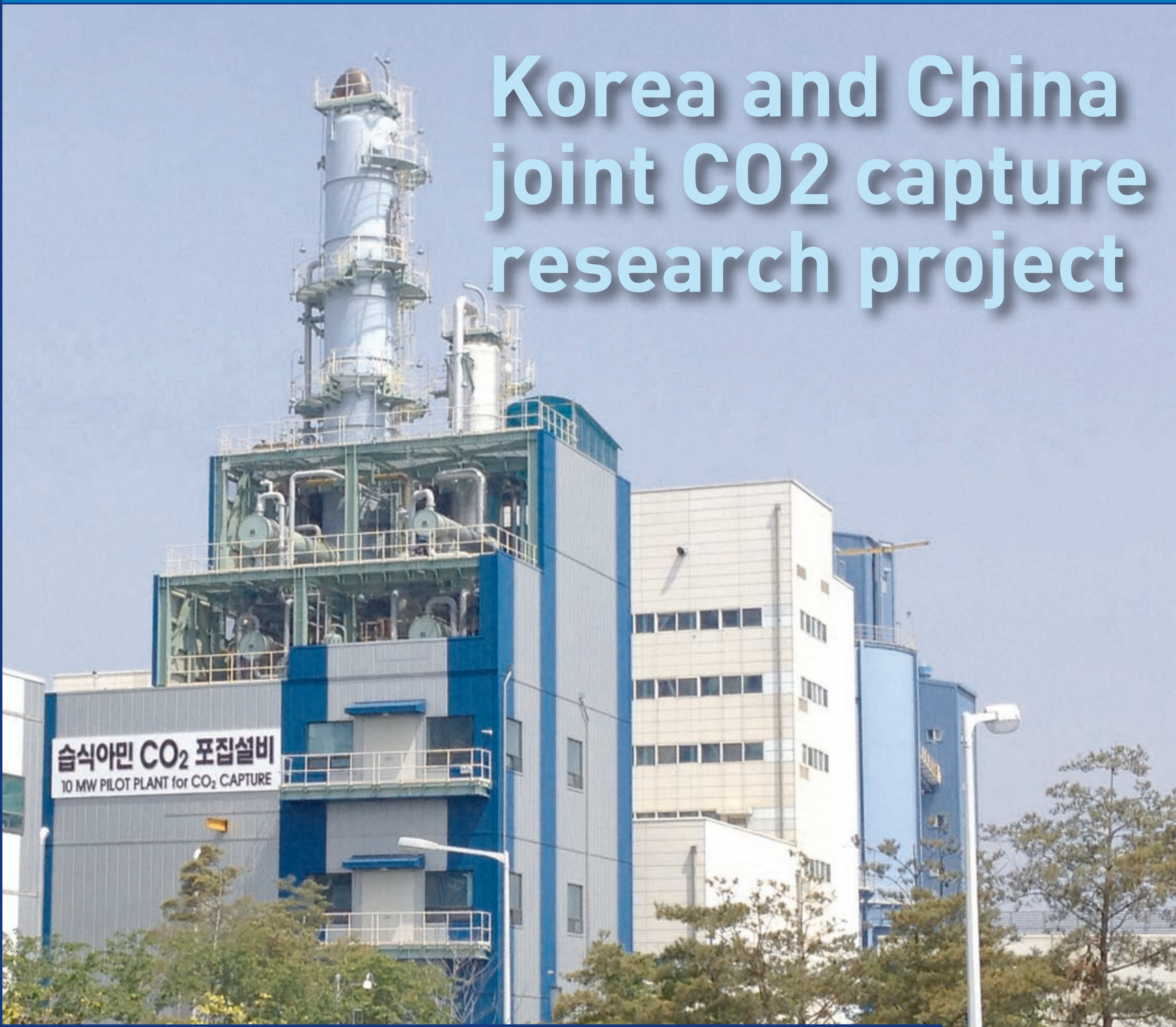
Korea and China joint CO2 capture research project



- Japan's big steps toward CO2-free hydrogen with CCS
- SCD Corporation's CO2 capture solvent and projects in Iran
- Photo-activated catalyst grabs CO2 to make ingredients for fuel
- Indian Oil and LanzaTech to build gas to bioethanol refinery

research*eu magazine special issue: The grand plan for carbon capture

The EU's results magazine, research*eu, pubished a special issue on carbon capture in July 2017, featuring a seres of articles including "Promoting European leadership in CCS technology" summarised here.

A project to establish a distributed world-class lab network will help Europe become a leading light in CCS research, opening up new commercial opportunities and providing a coordinated effort to tackling climate change.

While global demand for 'Carbon capture storage' (CCS) continues to grow, further development is urgently needed if this technology is to become viable and cost-effective.

To this end, the ambitious EU-funded ECCSEL (European Carbon Dioxide Capture and Storage Laboratory Infrastructure) project aims to establish European leadership in the field by developing world-class distributed lab infrastructure, accessible for industry and research. The project has created partnerships in order to avoid duplication and streamline joint funding for new research facilities across Europe.

Opening up research potential

'As a facilitator of world-class CCS research, ECCSEL will be able to engage with the European research community and other knowledge providers to offer expertise, advanced laboratories and test sites,' explains ECCSEL project director Sverre Quale from the Norwegian University of Science and Technology (NTNU). 'This is not something that would be possible by a single nation working alone.'

ECCSEL has since been transformed into a permanent European legal entity called ERIC (European Research Infrastructure Consortium). There is a main hub with national nodes, with around 50 distributed world-class laboratories and test pilots integrated into the structure. Completed and/or approved common investment plans total nearly EUR 90 million.

The lab infrastructure, which currently connects nine countries, will encourage the development of commercial CCS applications to come out of Europe. For example, engineering companies and technology providers will be able to promote the latest innovations and solutions to prospective partners, while plant owners and industrial partners will find it easier to invest in state-of-the-art CCS technologies.

'ECCSEL ERIC will also ensure that facilities required for conducting research in priority areas are available for the international research community,' adds Quale. 'By doing this, ECCSEL ERIC will contribute to pushing technological development beyond the current state-of-the-art, thereby accelerating the commercialisation and deployment of CCS.'

Environmental leadership

In addition to representing an economic opportunity for European business, CCS is also an emerging technology of geopolitical importance. 'In order to meet the 2 °C scenario of the IEA (International Energy Agency) and the Paris Agreement (1.5 °C), CCS must be developed and deployed within a decade,' says Quale.

In its most recent roadmap, the IEA provides advice on how CCS should be applied in various regions through to 2030 and 2050, while emphasising the importance of employing CCS extensively in power generation and industry sectors.

'In a European context, this means that aggregated CO2 amounts of 1.8 Gt until 2030 and 12.2 Gt until 2050 need to be captured and stored, taking into account expected growing demands. According to the IEA, 40.% of these emission cuts must take place in European industry. The challenges of climate change and the corresponding need for CCS research, innovation, technology development, testing and verification cannot be met by today's individually based research laboratories alone.'

As a result, the need for upgraded and new CCS research facilities has been widely recognised among stakeholders across Europe. This has been expressed through platforms such as the Zero Emissions Platform (ZEP) and the European Energy Research Alliance on CCS (EERA-CCS), and will now be realised through ECCSEL.

'Ultimately, our hope is that we will fulfil our vision, which is to enable low to zero CO2 emissions from industry and power generation in Europe, and to contribute strongly in combating climate change,' concludes Quale.

ECCSEL is coordinated by NTNU in Norway and funded under H2020-INFRADEV.

Other articles

The issue also features the following interviews and articles:

- Dr Jochen Ströhle of TU Darmstadt in Germany on 'Getting CCL technology ready for use at coal power plants'

- Dr Filip Neele of TNO in the Netherlands on 'Web-based tool helps site operators chose the safest CO2 storage option'

- Dr Stefan Penthor of TU Wien in Austria on 'Chemical looping combustion for CO2-neutral gas facilities'

- Novel nanomaterials bring CCS efficiency to the next level

- Using nanoscale ophiolitic rocks to capture and sequester CO2

- Cleaner coal power through combined technologies

More information

www.eccsel.org
cordis.europa.eu/research-eu

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Front cover:

The KEPRI / KOMIPO wet amine CO2 capture pilot plant with an annual capture capacity of approximately 70,000 tons was constructed in 2013 and is currently in operation in Boryeong, Korea

Back cover: SCD Corporation's CO2 capture facility at a Urea fertilizer plant in Iran

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Support grows for Carbon Capture incentives in the United States

The U.S. has an opportunity to harness the increasing bipartisan support for carbon capture by establishing incentives that would drive large-scale projects and infrastructure while achieving important national environmental, economic, and energy security benefits.

By Jennifer Christensen, Senior Associate, Great Plains Institute

Bipartisan support is growing in Washington for the Furthering carbon capture, Utilization, Technology, Underground storage, and Reduced Emissions (FUTURE) Act which would expand and reform the 45Q tax credit that was established to support the deployment of carbon capture and storage projects (Image: Wikimedia Commons)

At the federal level, a growing number of lawmakers from both political parties support legislation that would expand and reform the Section 45Q tax credit for carbon sequestration, and support legislation to provide carbon capture projects access to tax-exempt private activity bonds.

At the state level, a 14-state work group led by Wyoming Governor Matt Mead and Montana Governor Steve Bullock has recommended a package of federal incentives to advance carbon capture and carbon dioxide enhanced oil recovery (CO2-EOR) projects, as well as federal policies to support the buildout of additional CO2 pipeline infrastructure.

These efforts represent a growing chorus of state and federal elected officials, business leaders, and labor and nongovernmental organizations calling for incentives to spur capture deployment.

Background

The U.S. has made significant investments at the federal and state level in carbon capture to advance technology development through pilot projects and to deploy carbon capture more broadly at commercial scale. U.S. oil and gas companies also have a wealth of experience from decades of transporting and using CO2 in EOR operations. There are currently 4,600 miles of CO2 pipelines in the U.S.

Yet, the federal incentives available today are both unworkable and insufficient to drive deployment of commercial scale projects on the magnitude required to move toward the decarbonization of electric power and industrial processes, such as steel and cement production – an outcome that is only feasible if carbon capture is part of the solution.

The last decade has seen the development of numerous carbon capture projects in the U.S., most of which were not built due to financial obstacles, rather than technical challenges. While state and national leaders, companies, technical experts, and advocates have worked to get ‘steel in the ground,’ a challenging financing and commercial environment persists for investment in carbon capture projects.

The vast majority of existing carbon capture infrastructure in the U.S. was built for CO2-EOR projects. At a U.S. Department of Energy workshop last year, participants noted that CO2-EOR will continue to be the main driver for additional carbon capture infrastructure in the near-to-midterm. However, there remains a substantial cost gap between what EOR companies will pay for CO2 and the cost of capture, compression, and pipeline transport.

Federal incentives that have been introduced in the last year would substantially close that gap and enable critical infrastructure and projects to move forward. This includes the development of CO2-EOR projects using power plant and industrial CO2, which has the potential to generate jobs and revenue for states and the federal government, while significantly reducing net carbon emissions, even after accounting for the additional incremental oil produced.

Reformed, expanded 45Q tax credit could substantially increase investment

This summer, Senators Heidi Heitkamp (D-ND), Shelley Moore Capito (R-WV), Sheldon Whitehouse (D-RI) and John Barrasso (R-WY), along with a quarter of the U.S. Senate, came together in bipartisan fashion to cosponsor the FUTURE Act (S. 1535), which stands for Furthering carbon capture, Utilization, Technology, Underground storage, and Reduced Emissions. The FUTURE Act would expand and reform the 45Q tax credit that was established to support the deployment of carbon capture and storage projects (both through storage in saline formations and through CO2-EOR).

The reform and expansion of the 45Q tax credit is the highest legislative priority for carbon capture because of its potential to accelerate the commercial project deployment needed to advance the technology and reduce costs. The current 45Q tax credit fails to stimulate such deployment; it lacks sufficient value, and structural issues in the credit design create financial uncertainty for investors. As my colleague and Great Plains Institute Vice President Brad Crabtree shared with the Washington Post, "It was a well-intentioned tax credit, but it never worked out as intended."

At the federal level, an unprecedented bipartisan coalition called the National Enhanced Oil Recovery Initiative (NEORI) is working to reform and expand 45Q to remedy existing issues that would enable the tax credit to drive investment in carbon capture projects and infrastructure. NEORI includes top U.S. coal, oil, ethanol, industrial and technology companies, together with labor unions and national environmental organizations.

Specifically, the FUTURE Act modifies 45Q to:

• **Increase the credit dollar amount.** The current credit provides $10 per ton for qualified CO2 that is captured and stored through EOR, and $20 per ton for CO2 stored through other geologic storage. Under the legislation, the credit would increase to $35 and $50 per ton, respectively.

• **Lift the cap and extend the credit for new projects.** The current tax credit is limited to 75 million tons and is awarded on a first-come, first-served basis until all credits are claimed. This prevents project developers and investors from relying on the credit when making investment decisions. The bill provides certainty by ensuring that projects which commenced construction within seven years of enactment can qualify and claim the credit for 12 years after being placed in service.

• **Lower the threshold for industry participation.** By requiring that a facility capture 500,000 tons or more of CO2 annually, current law restricts most facilities in some industries from participation, notably ethanol and fertilizer production. This legislation reduces the eligibility threshold for industrial facilities to 100,000 tons to enable more industries and additional states and regions to benefit from the credit.

• **Allow for other types of CO2 utilization beyond EOR.** For projects that utilize CO2, the current credit is limited to EOR or gas recovery projects. The FUTURE Act expands the credit for other utilization and direct air capture projects, in addition to EOR.

• **Enable enhanced transferability.** The legislation enables entities that own the capture equipment and capture the CO2 to transfer the credit to any other entity within the chain of custody of that CO2, thus enabling greater flexibility in the use of the tax credit and a greater diversity of carbon capture business models.

These reforms would create the financial value and certainty needed by project developers and investors to enable and accelerate commercial carbon capture deployment across industries.

Access to private activity bonds would complement a reformed 45Q

In the Spring of 2017, U.S. Senators Rob Portman (R-Ohio) and Michael Bennet (D-CO) introduced the Carbon Capture Improvement Act (S. 843), a bill to allow carbon capture projects to use tax-exempt private activity bonds (PABs).

The bill would lower the cost of carbon capture by helping projects finance the purchase and installation of carbon capture equipment through tax-exempt PABs that can be paid back over an extended period. Under the bill, a facility that stores 65 percent or more of its emissions could finance 100 percent of eligible equipment. For a facility that stores less than 65 percent of its captured emissions, it would be eligible for such financing on a prorated basis.

Access to tax-exempt PABS alone would not lead to many additional carbon capture projects being financed. However, as a complement to a reformed and expanded 45Q tax credit, PABs have significant potential to leverage the number of projects that become commercially viable and proceed to construction—at little additional cost to U.S. taxpayers because extending PAB eligibility to carbon capture projects has a very small fiscal price tag.

Bipartisan support is building in Congress

The FUTURE Act described above underscores the gathering strength of political support for carbon capture. The statements made by individual senators at the bill introduction are a testament to the many benefits of carbon capture for the environment, economy, energy production and jobs, and to how carbon capture appeals to diverse political constituencies at a time when the U.S. is otherwise experiencing significant political polarization. The FUTURE Act builds on previous legislative efforts, including the Carbon Capture Utilization and Storage Act (S. 3179), which also had extensive bipartisan support in the previous session of Congress.

In the U.S. House of Representatives, Congressman Mike Conaway (R-TX) is expected to introduce in September the Carbon Capture Act—legislation similar to the FUTURE Act in the Senate. In the last Congress, Conaway's bipartisan bill had 50 cosponsors representing 26 states and spanning the entire political spectrum of the U.S. House.

Carbon capture incentives are garnering support across the country

Support for carbon capture incentives is also increasing among state, business, labor, and NGO leaders across the U.S. and illustrates the broad base of interests who recognize the importance of carbon capture for the country's energy future.

At the state level, the State CO2-EOR Deployment Work Group, led by Governors Mead and Bullock, recommended a package of federal incentives to:

• improve and expand 45Q

• provide a revenue neutral mechanism to reduce oil price risk in financing carbon capture projects by stabilizing the price paid for CO2 used in EOR

• allow tax-exempt PABs and master limited partnership status

The Work Group includes representatives from 14 states, private industry and NGO leaders, and CO2-EOR experts.

NEORI has also called for federal incentives and stated strong support for both extending and reforming the 45Q tax credit through the FUTURE Act and for making tax-exempt PABs available through the Carbon Capture Improvement Act.

Conclusion

The combination of federal incentives proposed in both chambers of the U.S. Congress has significant potential to accelerate carbon capture deployment in the U.S., both in key industrial sectors and electric power generation. If implemented, these domestic financial incentives will have important global implications as well, given the important international role that the U.S. has played in carbon capture to date.

More information

The Great Plains Institute co-leads the National Enhanced Oil Recovery Initiative with the Center for Climate and Energy Solutions, and staffs and facilitates the State CO2-EOR Deployment Work Group.

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California extends its cap and trade program

On July 26, 2017, California Governor Jerry Brown signed into law a bipartisan bill that extends the state's cap-and-trade program to 2030. Cap and trade is a key part of California's plan to reduce greenhouse gas emissions 40 percent below 1990 levels by 2030.

By Jason Ye, Center for Climate and Energy Solutions

The enacted bill makes design changes to the post-2020 carbon market, such as including a price ceiling, price containment points, additional limits to the number and location of offset credits, limits on who can set greenhouse gas emission requirements, and specifics on industry assistance factors.

Market-based policies offer a cost-effective way to reduce greenhouse gas emissions by creating financial incentives for covered entities to emit less pollution. Eleven U.S. states and many jurisdictions outside the United States have established market-based programs to reduce greenhouse gas emissions.

California was the first multi-sector cap-and-trade program for greenhouse gases in North America. The program was part of a suite of policies aimed at complying with state law AB 32 that required the state's emissions to return to 1990 levels by 2020. The existing cap-and-trade program covers nearly 85 percent of the state's total greenhouse gas emissions. California's program initially imposed an overall greenhouse gas emission limit that decreased 2 percent—below the emissions level forecast for 2012—annually from 2013 to 2014, and 3 percent annually from 2015 through 2020.

AB 398, the bill extending the program for 10 years passed with bipartisan support and more than two-thirds majorities in both the state Assembly and Senate. It authorizes the California Air Resource Board (CARB) to continue its cap-and-trade program to reduce emissions from 2021 to 2030, with the changes described below.

Price Ceiling

The bill directs CARB to establish a price ceiling, which is a standing offer to sell additional allowances into the program at a specified price. It's one way to provide certainty that an allowance price will never exceed a certain (ceiling) price. The existing program has a "soft price ceiling" in the form of the Allowance Price Containment Reserve. This reserve is filled with allowances from each year of the 2013–2020 program. If auction prices go above specified levels, the reserve allowances are auctioned, which provides some cost containment function, but does not absolutely guarantee an upper limit on prices. To date, reserve allowances have never been auctioned because prices have remained well below the specified levels.

To implement the new "hard price ceiling," CARB will use remaining allowances in the Allowance Price Containment Reserve at the end of 2020. If these allowances are exhausted, CARB will offer covered entities additional allowances at the price ceiling as needed to cover compliance.

The bill does not explicitly specify a price ceiling, but instead directs CARB to establish this price level —through the regulatory process—based on factors such as: the need to avoid adverse impacts on households and businesses, the social cost of greenhouse gases, the allowance price, auction floor price, the 2020 prices of the Allowance Price Containment Reserve, and potential for environmental and economic leakage.

Price Containment Points

The bill establishes two price containment points below the price ceiling and directs CARB to offer covered entities nontradable allowances at these containment points. The price containment points are similar to the existing Allowance Price Containment Reserve in that they are designed to help constrain compliance costs. However, the price containment points differ in that the prices will be made relative to the price ceiling while the strategic reserve has three tiers at specified prices and escalation rates. The price tiers were $40, $45, $50, in 2013, rising 5 percent annually above inflation. As of June 2017, the tier prices were ($50.69, $57.04, and $63.37).[1]

Each of the price containment points will be made up of one-third of available allowances in the price containment reserve at the end of 2017. In addition, allowances that are unsold for more than 24 months will be transferred to the Allowance Price Containment Reserve.

Offset Credit Limits

The bill limits the overall quantity of offset credits and the use of out-of-state credits. An offset credit is generated from a project not covered by the cap-and-trade program or required by any other program. These credits must demonstrate ownership and have verifiable greenhouse gas emission reductions. After CARB approval, these credits can be transferred and used by regulated sources to meet their greenhouse gas emission reduction obligations.

Under the current cap-and-trade program, offset credits can make up as much as 8 percent of the total amount of allowances used for compliance by a covered entity. AB 398 reduces this amount. From 2021 to 2025, up to 4 percent of a covered entity's compliance obligation can be met by offsets and half of these must be in-state or "provide direct environmental benefits" to California. From 2026 to 2030, up to 6 percent of a covered entity's compliance obligations can be met by offsets but again, at least half must benefit California.

Industry Assistance

The current regulation includes a provision for providing free allowances to manufacturing facilities in the state. The number that each facility receives is determined by its historic emissions performance relative to industry benchmarks, its exposure to trade competition from jurisdictions without carbon pricing, and other factors. The free allocation assistance began at a high level, to allow the industrial sector time to adjust its operations to the carbon price, and was to phase out after 2020. The program extension removed the phase out, and keeps industrial assistance at current levels through 2030.

Use of Revenues

The bill states that it is the intent of the legislature that revenues collected from the cap-and-trade program be used in accordance to specified orders of priorities, but the bill does not define how revenues should be used.

Existing laws require revenues collected from the current cap-and-trade program be deposited into the Greenhouse Gas Reduction Fund, and continuously appropriate 60 percent of the annual revenues for: transit, affordable housing, sustainable communities, and high-speed rail purposes.

Under the post-2020 program, revenues from the cap-and-trade program should prioritize:

1. Air toxics and criteria air pollutants from stationary sources

2. Low- and zero-carbon transportation

3. Sustainable agricultural practices that promote the transition to clean energy, water efficiency, and improve water quality

4. Health forests and urban greening

5. Short-lived climate pollutants

6. Climate adaptation and resiliency

7. Climate and clean energy researc

A companion bill, ACA 1, was also signed into law in July 2017. ACA 1 will put a ballot measure to state vote in June 2018 that will amend the state constitution to require a two-thirds vote in the legislature on appropriating revenues from the cap-and-trade program starting in 2024.[2]

Scoping Plan

The bill requires CARB to update its Scoping Plan by 2018 on how the state plans to achieve greenhouse gas reductions through 2030. The bill requires all greenhouse gas rules and regulations adopted by CARB to be consistent with the Scoping Plan. The existing law requires CARB to update its Scoping Plan every five years.

Local Air Pollution

AB398 prohibits the state's air pollution districts from adopting or implementing a carbon dioxide emission reduction regulation for stationary sources that are already covered by the state's cap-and-trade program.

Local air pollution issues are addressed in a companion bill, AB 617, which was signed into law alongside AB 398 in July 2017.[3] AB 617 increases monitoring of criteria air pollutants and toxic air containments, implements community air monitoring systems in disadvantaged communities, requires an expedited schedule for best available retrofit control technology at major emitting facilities, and imposes stricter penalties for those violating air pollutant regulations.

1. California Air Resources Board, 2017 Annual Allowance Price Containment Reserve Notice (Sacramento, CA: California Department of Environment, 2016), https://www.arb.ca.gov/cc/capandtrade/reservesale/2017_reserve_sale_apcr_notice.pdf.
2. Assembly Constitutional Amendment 1, Session 2017–2018, Chap. 105, Statues of 2017, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180ACA1.
3. Assembly Bill No. 617, Session 2017–2018, Chap. 136, Statues of 2017, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB617.

More information

The Center for Climate and Energy Solutions (C2ES) is an independent, nonpartisan, nonprofit organization working to forge practical solutions to climate change. Our mission is to advance strong policy and action to reduce greenhouse gas emissions, promote clean energy, and strengthen resilience to climate impacts.

www.c2es.org

Kemper County IGCC: Death Knell for Carbon Capture? NOT.

After almost 7 years of design and construction work, and over $7 billion spent, the much-publicized Kemper County coal gasification power plant will now run on natural gas without capturing any carbon. Does this mean carbon capture and storage for power plants is not ready for prime time?

By David Hawkins and George Peridas, Natural Resources Defense Council

A quick review of the facts shows the answer is no. The facts establish two things. First, the problems with the Kemper project have nothing to do with capturing CO2 from power plants. Second, other projects demonstrate that it is feasible to build CCS installations at commercial coal plants, on time and on budget. You can actually visit several successful projects around the globe that are operating and demonstrating beyond doubt that carbon capture technology at large sources works.

Carbon capture and storage (CCS) is a set of technologies that removes CO2 from large sources such as power plants, refineries, cement, chemical and ethanol production facilities, and allows it to be compressed and injected in geologic formations, where it will remain permanently trapped. There are 3 steps to CCS: capture, transportation and storage. The storage is the step that determines the long term fate of the CO2, and requires attention to pick the correct sites and operate them well. Transporting CO2 in pipelines is a mature technology and practice, with over 4,500mi of CO2 pipeline in the U.S. today. The capture, however, is almost always the most technologically complex and costly step.

Southern Company and Mississippi Power's Kemper project has suspended operation of the gasification portion of the facility, putting the CCS project in doubt (Image ©Mississippi Power)

The reason is that CO2 in industrial stacks does not occur in isolation. Air (consisting of roughly 80% nitrogen and 20% oxygen) makes up a significant part of many exhaust streams. With some exceptions, such as ethanol production facilities that produce relatively pure CO2 streams, CO2 from other facilities needs to be separated from other gases such as nitrogen, oxygen and steam. This is commonly done using a chemical that likes to "grab onto" the CO2 that has been produced after the coal or gas have been burned. The chemical is then made to release the CO2 it by heating it (read more here if interested).

For coal power generation, CO2 can be captured using two approaches: in one approach, applicable to most existing power plants, equipment is used to separate the CO2 from the exhaust gas of the power plant; in the second approach, a new power plant can be built from scratch using a process that first turns coal into a fuel gas that is then treated to produce separate streams of hydrogen and CO2 – a process known as "gasification".

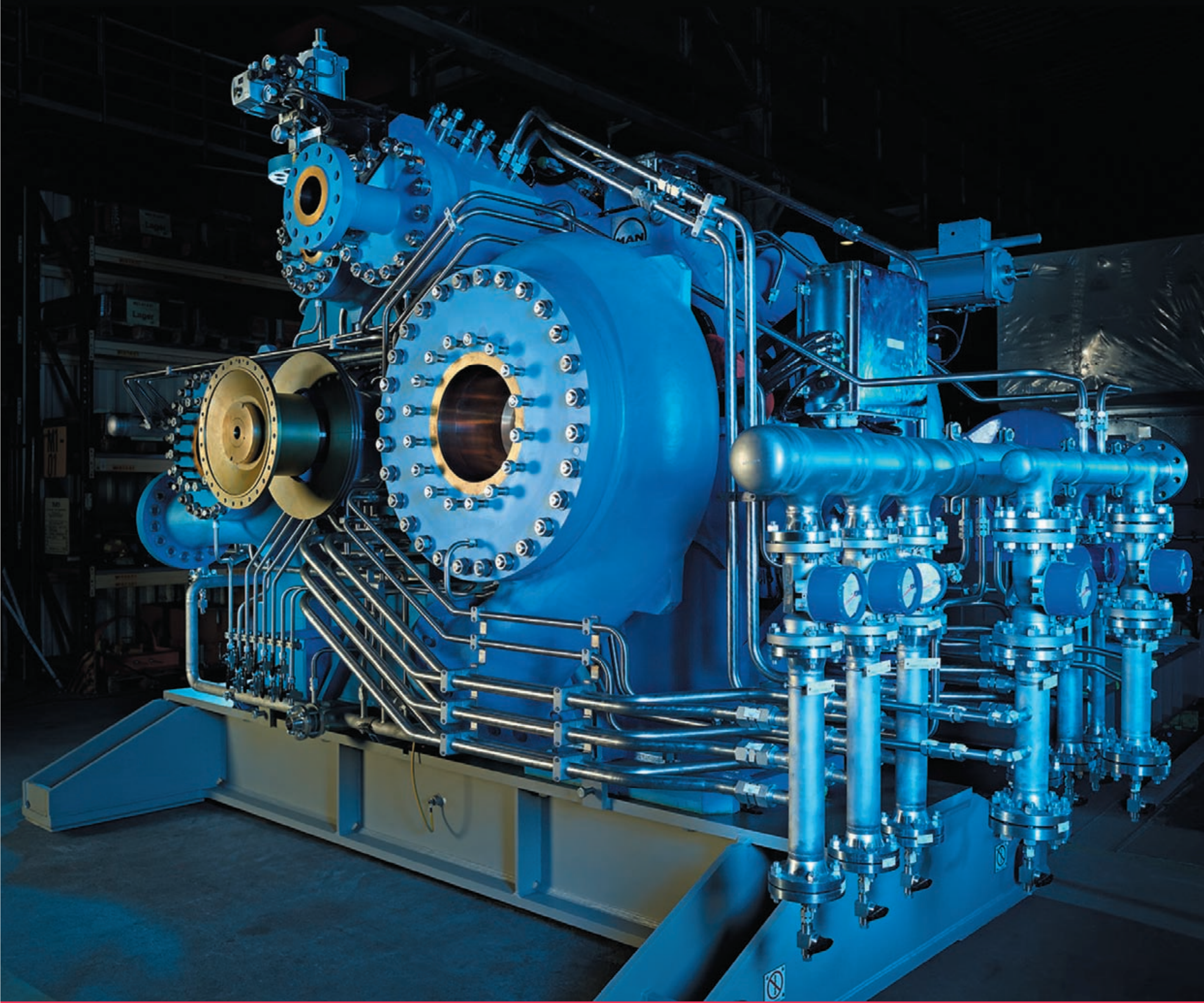
A gasifier supplies heat under pressure in the presence of steam and air or pure oxygen. Solid coal is turned into a gas called "syngas" (synthesis gas), which consists primarily of hydrogen and carbon monoxide. The hydrogen can be used as fuel for turbines to generate carbon-free power, while the carbon monoxide can be "shifted" to carbon dioxide which is then captured, transported and injected underground. Commercial gasification systems have been in operation at industrial facilities for decades.

Why go through all these added steps in gasification? Until fairly recently, the first approach—using a CO2 scrubber at the tail end of a conventional power plant—seemed more expensive due to high energy penalties and other factors. Today, the technology to scrub CO2 from the stack has matured to the point that several companies are offering commercial warrantees, and full-scale commercial coal plants are using them.

So there is no inherent advantage to gasification any more, except if you seek to commer-

Actions speak louder than words

High pressure CO_2 gas compression



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cialize your own gasifier technology and sell it more broadly for production of chemicals, for example. That was Southern Company's strategy with Kemper. It proved to be an overly ambitious one.

What was responsible for this spectacular turn of events and the collapse of this much-publicized project? There are a number of factors, it seems, that have to do with unrealistic ambition, breach of standard project management practice and protocol and faulty housekeeping. An independent company conducted a "Prudency Evaluation Report" for the Mississippi Public Service Commission, and the document reveals in some detail what went wrong.

First and foremost, the project was unrealistically ambitious. Kemper was an attempt to scale up and commercialize a new gasification technology: the TRIG (Transport Integrated Gasification) technology. The technology was developed by the KBR Company and Southern Company, with assistance from the Department of Energy. The predecessor demonstration project for this novel system was only 7MW in size. Going to 582MW for the full-size plant as Southern did is a very ambitious scale-up endeavor, which breaks cleanly from standard engineering practice. And Southern was not able to do this successfully.

Second, the company brushed aside common project management practice in order to avoid losing a federal tax credit ($133million 48A Phase I Investment Tax Credit established by the Energy Policy Act of 2005) that required a commercial operations date no later than May 11, 2014. Instead of moving the date as a project this complex dictated, the company decided to proceed with engineering, procurement and construction in parallel, in what team members dubbed a "compressed schedule". This essentially means that you are designing at the same time as you are building, which of course leaves you highly vulnerable to both engineering failures and cost overruns.

Third, the company overlooked potentially valuable learnings from another gasification facility by Duke Energy at Edwardsport, Indiana. The actual nature of the learnings is concealed in the text of the prudency report, presumably for confidentiality reasons.

Fourth, even though the company used specialized industry scheduling software, it decided to "manually resource load (i.e. construction labor and bulk commodity amounts) using a stand-alone spreadsheet". This contributed to the now infamous cost overruns, as the team was unable to see and track the growth in commodity requirements.

The company was sailing uncharted waters; but it is important to realize that it didn't have to. First-of-a-kind plants carry a significantly higher risk factor for developers, and this case was no exception.

The WA Parish project in Texas, operated by Petra Nova, a joint venture between NRG and JX Nippon Oil & Gas Exploration is operating successfully

However, several manufacturers have had commercial, off-the-shelf offerings for gasifiers on the market for years now, with accompanying performance warranties. Southern chose to pass on those, and to embark on the far more ambitious journey of commercializing their own, presumably with future business opportunities in mind.

The key fact to emphasize is that the Kemper project failure is not due to any problem with the equipment required to capture CO2. All of the problems are due to the system components upstream of the capture stage. Other projects demonstrate that capturing CO2 from coal plants is indeed feasible. Two companies are now operating coal plant units with CCS in North America, using technology that removes carbon dioxide from the tail end of the conventional power generation process using chemical scrubbers rather than resorting to gasification.

The first of these projects is the Boundary Dam project (you can see a virtual tour here) operated by SaskPower in Saskatchewan. It was a retrofit and concurrent expansion and modernization of an existing coal plant unit, and began operations in October, 2014. The 120MW project can capture up to 90 percent of the unit's CO2 and was completed in a timely fashion, with minimal cost overruns (more details here).

The total cost for the retrofit was approximately $1.5 billion, of which $800 million was for the CCS process, and the remaining $500 million for retrofit costs. There was some debate surrounding the availability of the unit and its peak CO2 capture performance, which were lower on occasion during the first few months of operation. This can be chalked up to routine start-up issues that are inherent in any new unit's operations. Today, the unit is consistently achieving or exceeding its design specifications and by May, 2017 had captured approximately 1,579,000 tons of CO2 since it began operations. Saskpower publishes a monthly performance update for the unit (see, for example, here and here).

The second of these projects is the WA Parish project in Texas, operated by Petra Nova, a joint venture between NRG and JX Nippon Oil & Gas Exploration. This is also a retrofit of an existing coal plant and is twice the size of Boundary Dam. It captures 90 percent of the CO2 from a 240 MW flue gas stream at a rate of about 1.6 million tons per year.

The Petra Nova project came online in late 2016, on budget and on schedule, at a cost of approximately $1 billion. In late July, 2017, the people closest to the project were reporting "so far, so good", with the pant capturing about 94 percent of the CO2 it processes and more than 700,000 tons of CO2 captured in total since commencement of operations.

So, there are lessons to be drawn from the Kemper project experience. Kemper tells us that scaling up a novel gasification approach from a very small demonstration project to a very large commercial unit is very risky. The project also reminds us that there is no substitute for solid project planning and execution. But the conclusion is not that CCS is a flop.

More information

www.nrdc.org

Japan's big steps toward CO2-free hydrogen with CCS

With the unchanged situation of nuclear power and the slow progress of renewable energy, Japan will head toward utilization of hydrogen made from domestic lignite coal for its clean energy needs and a new deployment of carbon capture and storage (CCS) is receiving attention as a key technology to revitalize towns which once flourished with coal.

By Terufumi Kawasaki, President, Global Environment Information Service, Japan

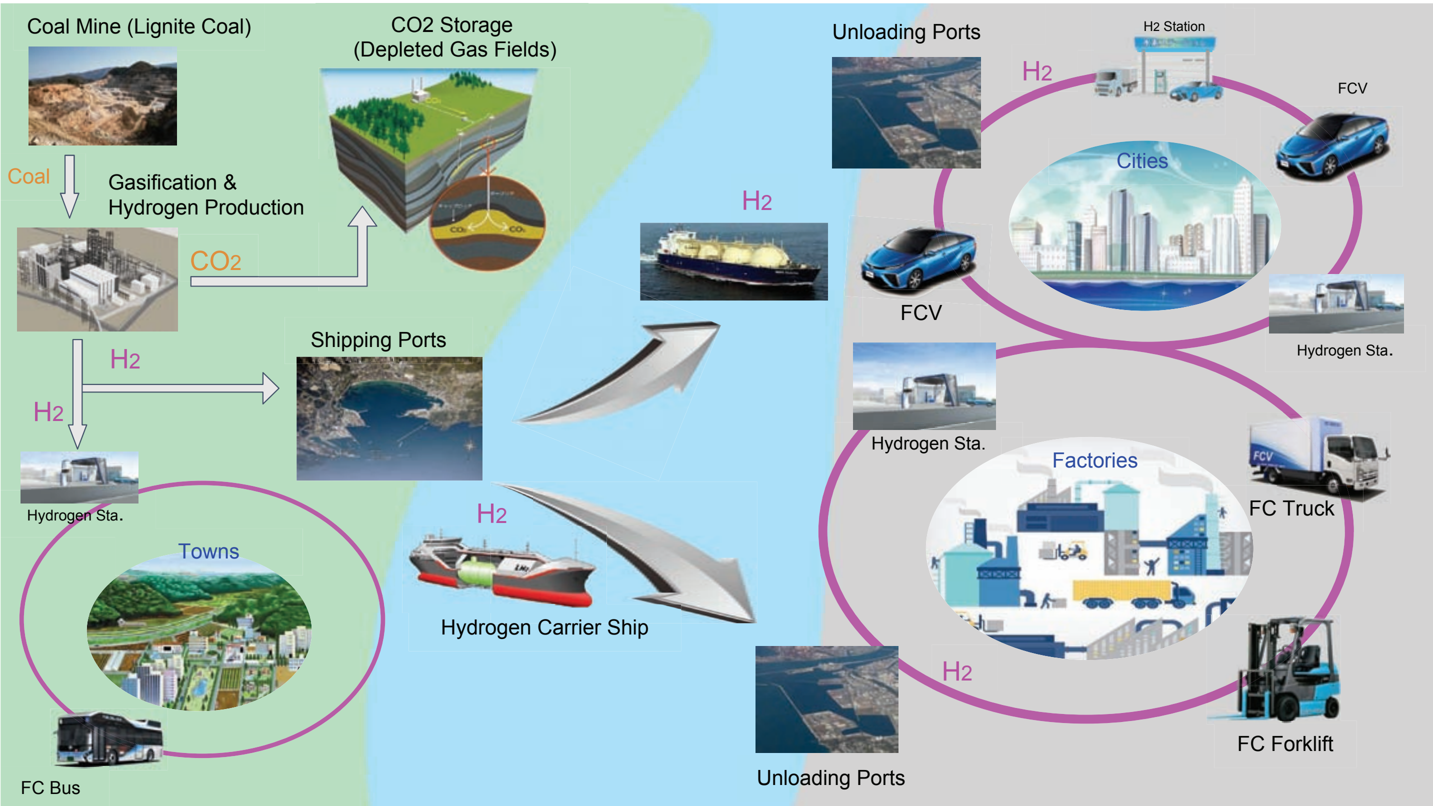

Figure 1 A schematic of a hydrogen society

Six years have passed since all nuclear power stations were shut down due to the Fukushima accident in 2011. Among 49 existing units of nuclear power generation, only five units, generating in total just four gigawatts, are commercially operating as of July in 2017. Operation of the others, which can generate 45 gigawatts, is still suspended for safety reasons and high public unease.[1]

This keeps Japan's energy dependent on fossil fuels, emitting much more CO2 than expected. On top of that, only one demonstration project of CCS in Japan, where CO2 is stored at an annual rate of 100,000 tons in saline layers under the sea bed of the northern area, just started injecting CO2 in April, 2016 and is scheduled to continue monitoring it until the end of 2020.[2] It will take a long time to assess its feasibility.

Japan's government has adopted a 'Feed-in Tariff' (FIT) policy for renewable energy such as solar and wind power, and accelerated the introduction of CO2-free energy.[3] As a result, it accounted for 4.7 % of the total power generation as of March in 2016.[4] On the other hand, the purchase price has been reduced year by year in order to keep an appropriate range of electricity prices. As a matter of fact,

1. Japan Nuclear Technology Institute, http://www.gengikyo.jp/english/index.html
2. Japan CCS Co., Ltd., http://www.japanccs.com/en/business/demonstration/
3. The Ministry of Economy, Trade and Industry (METI), http://www.meti.go.jp/english/policy/energy_environment/renewable/
4. METI, Japan's Energy White Paper 2016, http://www.enecho.meti.go.jp/en/

people pay more than a 10% additional fee for renewable energy. The buying price of solar power, for example, is now 28 yen per kilowatt hour (kWh), which is two-thirds of that in 2012.[5] Hence, a significant increase of renewable energy will not be expected hereafter.

This is why a new energy source, carbon-free hydrogen, is receiving more attention nowadays together with further discussion on CCS.

Fuel Cell Vehicles to reduce CO2 emissions

In accordance with the Paris Accords, Japan should take any types of measures to achieve its target. An important field is transportation since it consumes a lot of fossil fuel. This sector accounted for 16.7 % of total CO2 emissions in FY 2015, following the power generation and industry ones.[6]

Big automobile companies have invested a lot to develop electric vehicles (EVs), but they also aim at fuel-cell vehicles (FCVs) because EVs are useless for CO2 emissions reduction if they run on electricity generated mostly from fossil fuels. FCVs could directly and indirectly achieve no emissions of CO2 with the supply of CO2-free hydrogen.

Initiatives for a Hydrogen Society

Last year, Japan's Ministry of Economic, Trade and Industry (METI) issued a report on a feasibility study of a hydrogen society, ranging from residential-use fuel cell systems to private and industrial FCVs.[7] It says that the hydrogen cost should be around 500 yen per kilogram to maintain the business of hydrogen stations for FCVs. The calculation is made as a function of the number of FCVs and hydrogen stations as well as the capital and operational cost of the stations. The desirable cost of hydrogen seems to be so challenging.

This April, the Cabinet decided to finalize a strategic plan toward a hydrogen society by the end of this year. The prime minister will promote integration of individual projects on a hydrogen society which have already progressed around the country.

Private FCVs running on the streets numbered more than 600 in March, 2016. Toyota Corporation released a commercial version called Mirai or 'Future' in 2014, followed by Honda in 2016. METI now has a roadmap for 40,000 FCVs in 2020 and 200,000 in 2025. Hydrogen stations, fueling FCVs in big cities, totaled around 90 in 2016, developed by several companies related to the petroleum, steel and hydrogen supply businesses. Moreover, an industrial use of FCVs, forklifts, has been demonstrated in Kansai International Airport in Osaka since 2015.

This gives us a perspective that Japan is more advanced in scale compared with similar demonstrations in California, USA and Germany. No other country but Japan is in a good position to step up to a hydrogen society, which consists of facilities producing, supplying and utilizing CO2-free hydrogen.

Production of CO2-free hydrogen

Most hydrogen is now produced as a by-product gas of oil refineries, which sets the current price range of hydrogen around 1,000 yen per kilogram or more. Needless to say, it is not CO2-free. One practical idea to achieve 'CO2-free' is electrolysis of water using electricity generated by renewable energy. This CO2-free process, however, includes a tough challenge of cost reduction. Electrolysis methods are well known to require a lot of electricity, and electricity from renewable energy is the most expensive among the primary energy resources. This double high-cost structure must be tough to resolve in the short term.

Another idea is gasification of lignite coal together with CCS. Low-grade coal could be supplied at a price lower than any other kind of fuel in the world, which is a good advantage in terms of cost minimization. A governmental research institute, the New Energy and Industrial Technology Development Organization (NEDO), adopts this approach together with some Japanese companies and Australian counterparts.[8]

Gasification of lignite coal produces hydrogen at an Australian site, and CO2 yielded in the process is conveyed to CCS sites through a network of CO2 pipe lines called Carbon Net. The CO2-free hydrogen is exported to Japan, liquefied before shipping. The project has a demonstration plan to annually produce 150,000 tons of hydrogen in 2020. Several hundred million yen will be invested in total. An implementation body of the research project was established in 2016, consisting of four major companies: Kawasaki Heavy Industry, Iwatani Corporation, J-power and Shell Japan.[9]

It seems to be practical since it is very similar to the existing trading system of natural gas. However, there are some unknown factors in the project. One is the gasification technology of lignite coal, which contains a lot of water and volatile gases, and another is the long transportation route of liquid hydrogen, which must be kept at less than minus 253 degrees Celsius. Lastly, it should be provided at a competitive price. In addition, not technically but ethically, we will have to discuss whether or not it should be acceptable for Japan to consume a lot of hydrogen while leaving so much CO2 in Australia.

Three key words to achieve the coal-to-hydrogen business

1) Domestic lignite coal and depleted gas fields

A Japanese entrepreneur has just started a project where CO2-free hydrogen can be produced at a considerably low cost.[10] Nobody except him has found such an appropriate site inside the country.

Domestic lignite coal is mined by open casting in a northern area of Japan, gasified and changed into hydrogen gas at the site. Liquid hydrogen isshipped from a port nearby. Destinations in big cities like Tokyo are just several hundreds of kilometers away, which is just one tenth of the transportation route from Australia. This must be a good advantage in reducing the total cost, which includes the building of hydrogen carrier ships, power consumption and hydrogen loss during marine transport.

One more advantage is that the coal mine is just tens of kilometers away from the depleted

5. Tokyo Electric Power Company, http://www.tepco.co.jp/pg/consignment/fit/pdf/h29price.pdf (in Japanese)

6. Ministry of the Environment, Japan, National Greenhouse Gas Inventory Report of Japan, http://www-gio.nies.go.jp/aboutghg/nir/2017/NIR-JPN-2017-v3.1_web.pdf

7. METI's Research Report (FY 2015), http://www.meti.go.jp/meti_lib/report/2016fy/000227.pdf (in Japanese)

8. The New Energy and Industrial Technology Development Organization(NEDO), http://www.nedo.go.jp/news/press/AA5_100396.html (in Japanese)

9. Kawasaki Heavy Industries, Ltd., http://global.kawasaki.com/en/corp/newsroom/news/detail/?f=20160401_4614

10. Nikkei Ecology, Trends & News, June, 2017 (in Japanese)

Figure 2 A picture of IHI's gasification plant in Indonesia (50 tons of coal/day

natural gas fields, which are more suitable for CO_2 storage than saline layers, because they do not require a lot of technical surveys to ensure the injection. The layers once stored natural gas. A company engaged in the natural gas business has retained geological information about the layers, with which the storage capacity of CO_2 can be reasonably estimated. Even the risk of CO_2 leakage can be discussed based on the data.

The site is in the northern area of Hokkaido, which once flourished with so-called 'black diamonds' and now suffers depopulation. Municipalities expect to revitalize towns and create jobs through the project. This is a hopeful sign of public acceptance.

2) Gasification Technology of lignite coal

Japan's major heavy industry company, IHI, which supplies a wide variety of power generation facilities, has developed a unique fluidized bed to gasify lignite coal, incorporated with a recirculation line of bed material to make up for heat loss by water of lignite coal.[11, 12]

The water contained in coal is also utilized as a chemical component necessary for the gasification reaction, which enables the system to achieve a high conversion efficiency of coal to hydrogen. In addition, it is designed to be operated at atmospheric pressure in order to reduce the costs of materials, construction and maintenance.

A demonstration plant with a capacity of 50 tons of coal per day was completed in Indonesia in 2015, operated using lignite coal mined in the country in cooperation with Indonesian companies and the government. IHI issued the latest report this month, showing that it kept a stable operation for 4,400 hours, including more than 1,000 hours of continuous operation and that the syngas included hydrogen at levels of more than 50 % of the total amount.

The plant kept achieving stable performances with a sudden change of coal from one kind to another during the operation, which indicates it has adaptability to various kinds of lignite coal. The demonstration tests in Indonesia convinced IHI to scale up to a commercial plant in Japan.

3) Cost Estimation

The project leader is Mr. Toshihiko Miyagawa of Sakura Business Consultant Co., who began his career in engineering and pursued a career in governmental administration both domestically and overseas, particularly in the energy and resources field. This is one reason why he was able to create this project.

He undertook some feasibility studies on the project last year, joined by several Japanese companies including IHI. The initial target of hydrogen production was set at 15,000 tons per year, equivalent to the consumption of 100,000 FCVs. The amount of coal necessary for gasification is 300,000 tons per year, and the coal mine has 20 years' worth of reserves. IHI provided capital and operational cost estimates of the gasification facility. The depleted gas fields annually store tens of thousands of tons of CO_2.

Based on these conditions as well as the cost evaluation of the liquefying facility and transportation, liquid hydrogen is estimated to cost 580 yen per kilogram at the CIF base. This is around half of the current market price. In addition, it is very close to the desirable cost,

11. IHI Engineering Review, vol. 45, No.1, 2012, https://www.ihi.co.jp/.../fae45aac0eb82bef2ca20cf8cc2cb0f0.pdf
12. IHI, a technical material released in July, 2017 (in Japanese)

500 yen per kilogram, which is cited by METI as a target price that could commercialize hydrogen stations. It is notable that hydrogen can be supplied at such a reasonable price.

He reveals even the internal rate of return, IRR, of the project. It is 19.7 %, which means the project is worth enough to go ahead. It must be time for Japan to step up to a futuristic hydrogen society in 2020.

Summary

There is a new energy project, where CO2-free hydrogen can be supplied at considerably low prices, by gasifying domestic lignite coal and deploying CCS in depleted gas fields near the coal mine. This will break the mold in the energy industry in several years.

In the 2020 Tokyo Olympics, people will be able to see a futuristic model society where FCVs run on the streets in urban areas, playing an important role in keeping our cities clean and sustainable, and in the countryside, newly installed facilities of hydrogen production will create jobs and revitalize coal towns which once flourished. This new model of energy infrastructure will change the world in the near future.

More information

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Silixa – acoustic sensing with much less noise

Silixa has developed a fibre optic cable for recording seismic in wells, which is 100x more sensitive than the current Silixa iDAS seismic system, leading to improved imagery of the sub-surface.

By Karl Jeffery

UK company Silixa has developed a way to treat fibre optic cable so it is much more reflective – so it can record seismic data in wells with 100 times more sensitivity.

Companies record seismic data in wells so they can monitor what is happening in the reservoir around the wellbore.

One of the first installations is in Australia, where the well is being used to inject carbon dioxide into a reservoir. With repeated seismic surveys, it is possible to monitor the spread of the CO2 plume within the reservoir. The CO2 does not show up directly on the seismic image, but shows up indirectly, as extra distortion on the image.

The well is near Melbourne, run by the Otway Research Facility, part of research organisation CO2CRC.

The company has been selling IDAS services for four years on over 80 wells, onshore and offshore.

This newly developed technology is called “Carina” that increases the sensitivity by 20 dB.

Silixa does not disclose the details of how it is treating the fibre optic cable, but the result of its treatment is that more of the light going through the fibre is reflected by the seismic events. This allows the upgraded laser interrogator to deliver the improved sensitivity signal.

Silixa in general is seeing growing interest from the industry in installing fibre optics in wells for permanent reservoir monitoring.

For seismic monitoring however, it is much cheaper to trench the fibre at surface, than install in a well, says Mick Longton, commercial director of Silixa.

The fibre optic system provides a geophone equivalent repeatable seismic recording at a much cheaper cost than using geophones down the well on wireline, which to date has been the standard way to record seismic inside wells.

The technology might make it viable to do permanent monitoring on some wells for the first time – it would probably be too expensive to monitor something like CO2 injection using conventional surveys, he says.

The challenge now becomes changing industry culture – because the industry is very accustomed to recording well seismic using geophones on wireline. “Is the industry open enough to recognise a geophone isn't the only answer?” Mr Longton asks.

Mick Longton, commercial director of Silixa.

Silixa uses its fibre for a range of different areas in the oil and gas industry, including frac operations and monitoring well integrity. It also has a business unit focusing on other industries, with applications such as leak detection, power cable monitoring, and flowrate measurements.

More information

www.silixa.com

Korea and China research advanced CO2 capture technology

The Korea Electric Power Corporation Research Institute (KEPRI) and the Huaneng Clean Energy Research Institute in China have begun a joint international research project for the development of post-combustion CO2 capture technology.

By Ji Hyun Lee, KEPRI and Gao Shiwang, CERI

Huaneng CO2 capture demo plant 120,000 tCO2/y (Shanghai, China)

On April 2017, the Korea Electric Power Corporation Research Institute (KEPRI), Korea Midland Power Co., Ltd., (KOMIPO) and the Huaneng Clean Energy Research Institute (Huaneng CERI) of China commenced a joint international research project for the development of post-combustion CO2 capture technology of world-class standards.

KEPRI, the central research institute of KEPCO (the largest electric utility in South Korea), undertakes research and development of technology for various purposes, such as environment-friendly energy generation, reduction of greenhouse gases and renewable energy. KOMIPO, the main power generation subsidiary of KEPCO, currently operates six thermal power plants and various renewable energy facilities in south Korea. CERI is a clean energy R&D institution directly under China Huaneng Group (CHNG), the largest of the 5 major power generation companies in China. The institute is currently conducting research on clean energy, renewable energy and greenhouse gas reduction.

The joint international research launched in the current year follows the technical exchange MOU for the clean energy development signed between KEPCO and CHNG in 2014. The research is planned for a period of 27 months with total research funds of approximately 4 million USD.

The current status of CO2 capture technology development in South Korea and China as well as the key points of the joint international research between KEPRI-KOMIPO-Huaneng CERI are as follows.

Status of Key CO2 capture technology development in KEPRI and Huaneng CERI

South Korea and China invest greatly into various research and development to reduce greenhouse gas emissions resulting from the heavy reliance on fossil fuels for power generation in both nations. For example, KEPRI and KOMIPO in South Korea have independently developed the low-energy amine-based CO2 solvents (KoSol series) through the research projects that began in the year 2000.

Based on these developments, a wet amine CO2 capture pilot plant with an annual capture capacity of approximately 70,000 tons was constructed in 2013 and is currently in operation in 2017 (location: KOMIPO Boryeong power plant). Recently, the excellent CO2 capture capabilities of the solvents were confirmed through 5,000 hours continuous operation. A separate compression process is applied for the captured CO2, which is then stored to be sold for industrial and agricultural uses.

CHNG is also conducting substantial research in the development of CO2 capture technology. Especially noteworthy is the construction and operation of a demo plant capable of approximately 120,000 tons of annual CO2 capture in 2009, which is the largest in Asia in terms of CO2 capture capacity (location: Shidongkou power plant in Shanghai). In particular, CO2 capture technology developed by Huaneng CERI is considered to be highly economical in terms of cost of CO2 avoided.

The KEPRI/KOMIPO wet amine CO2 capture pilot plant with an annual capture capacity of approximately 70,000 tons was constructed in 2013 and is currently in operation in Boryeong, Korea

Research Content

The joint international research project plans to utilize the pilot post-combustion CO2 capture plants developed and operated by KEPRI/KOMIPO and the Huaneng CERI to conduct cross-performance evaluation on the advanced CO2 solvents and processes developed by each company, securing a track record for entry into the global CO2 capture technology market and objectively demonstrating the technology reliability. (See Figures)

For the first time in the field of international CO2 capture technology research, cross-evaluation of solvent performances in different capture plants, with the CO2 solvents developed by KEPRI (KoSol series) being tested in the Huaneng Shidongkou CO2 capture plant, and the solvents developed by Huaneng CERI (HNC series) being tested in the Boryeong CO2 capture plant, will be performed. In addition, development is underway to substantially improve the performance of specialized capture technology both institutes possess (KEPRI: development of an accelerator for faster CO2 absorption & regeneration, Huaneng CERI: development of additives to improve long-term solvent durability).

With the cross-performance evaluation and joint advancement research using the pilot-scale post-combustion CO2 capture plants as a basis, KEPRI/KOMIPO and Huaneng CERI will conduct SWOT (Strengths-Weaknesses-Opportunities-Threats) analysis on the CO2 capture technology of both institute. Using the analysis results, optimum CO2 capturing solvent & process development and joint intellectual property rights will be secured to establish a foundation for entry into the global CO2 capture technology market in the future.

Future Prospects

As of 2017, wet amine-based post-combustion CO2 capture technology has already been technically verified through the operation of commercial CO2 capture technology plants with an annual capacity of over 1 million CO2 tons in countries such as the U.S. and Canada. Therefore, the future research and development should be aimed at minimizing the energy penalty in capture process operations, as well as reducing the capital & operating expenditure of the CO2 capture technology.

The collaboration of China's great potential and economic competitiveness in the CO2 capture technology market and Korea's advanced engineering technologies in the field of post-combustion CO2 capture processes is expected to produce great synergy in the CO2 capture technology field for the benefit of both nations, as well as generating a large ripple effect in related research globally.

More information

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SCD Corporation's CO2 capture solvent being tested in Iran

SCD Corporation in Iran has developed a proprietary solvent which it is currently testing at two projects.

By Sam Salimi Beni, VP-CDR Projects, SCD Corporation

The importance of capturing carbon is not in doubt anymore. In fact, many reputable world bodies including IPCC, have time and again reiterated on the significant and undeniable role of CCS in combating global warming. But there are definitely hurdles as to why implementation of CCS projects is happening very slowly. Mainly CCS technology is identified with two main issues:

- High CAPEX & OPEX
- Energy intensive

CO2 recovery plant towers at Besat Power Company

Most of the well-known commercially available technologies tend to bring the cost of capture in the range of \$50-\$70 per ton of CO2, and that would mean for instance that in the case of EOR application it would cost at least \$15 to \$21 - given that it would take at minimum 0.3 ton of CO2 - to extract one barrel of oil, and at current prices of oil, this is not a very attractive proposition.

In addition to the cost challenge comes the reality of avoided CO2, which is translated into its own cost element. The current solutions for carbon capture, which are almost entirely based on chemical absorption, are very much energy intensive, with consumption figures reported in range of 2.2-3.6 GJ/ CO2 ton. The latter is at odds with the whole concept of carbon capturing; if a technology that promises to lower emissions has a relatively modest avoided CO2, is it really worth it?

Well, a new addition to the world of carbon capturing is declaring that CCS is viable and it can be implemented at a fraction of the cost, using state of the art Iranian technology. This report aims at introduction of a new player in the field of carbon capture, SCD Corporation, an Iranian knowledge based organization with patented know-how of carbon dioxide production & recovery spanning over three decades.

One of the most prominent economies in the Middle East and strong supporter of Paris agreement in the region is that of Iran. According to official statistics, Iran has continually been ranked as one of the top ten carbon emitters in the world. The Iranian economy is heavily dependent on its oil & gas industry, and thus carbon management is seen as a critical success factor in business continuity. Although the journey towards a low carbon economy is long, Iran has taken the first steps toward such economy by embracing carbon capture, utilizing the expertise and knowledge existing in its economy.

As of today, two small scale projects have been awarded to SCD Corporation on an EPC basis. SCD Corporation has carried out extensive research on post combustion carbon capture technology for the past 30 years. It's worth nothing that it is also the largest CO2 manufacturer in Iran, thus, perfectly situated to conduct time consuming carbon capturing research on its plants. PCC technology developed and commercialized by SCD is based on chemical absorption with a patented solvent which is the pinnacle of SCD's Carbon Dioxide Recovery (CDR) solution. The solvent is commercialized as MPŋ®, and it gets customized according to each project's composition of flue gas. In addition to this,

SCD has been able to design a very specific configuration which lowers the energy consumption much below current energy performance reported on commercially available technologies.

Iran's CDR experience

CDR plant at Besat Power Company

The project at Besat Power Company came to life after almost 2 years of negotiations and careful analysis of technical requirements. Finally in August 2009, Besat Power Company awarded SCD Corporation an EPC contract after the completion of the bidding process for its RFP for a CDR plant to be built at its site on Southern part of Tehran with extraction capacity of 15000 tpa. The plant was designed, licensed and built by SCD within 8 months from the day of contract signage, which in itself is a millstone in the world of project management.

The CDR plant at Besat power Company, consumes about 40% less electricity per ton of CO_2 in comparison with conventional CO_2 extraction systems, mainly due to the fact that SCD technology utilizes heat integration for liquefaction, a system based on ammonia absorption which heavily contributes to low energy consumption.

One of the advantages of this plant is the utilization of a single stage compressor with compression rate of 2, leading to significant reduction of power consumption of the compressor by reducing the discharge pressure to 12 bars which becomes a possibility due to the Ammonium absorption system.

SCD CDR's technology is developed with a philosophy of lowering operating cost. For instance, most technology providers tend to design CO_2 absorber & stripper columns with higher pressure drop, a result of smaller towers' diameters, in an effort to minimize fabrication costs. This leads to increased electricity consumption, since a more powerful blower is required in order to satisfy high pressure drop of flue gas stream throughout the system. At SCD, the focus is on low pressure drop which leads to lower electricity consumption. Although, the size of packed towers would increase, the company has been able to offer CO_2 turnkey solutions much below prices requested by international competition.

The CDR plant at Kermanshah Petrochemical Industrial Complex (KPIC) recovers 132 MTPD from the stack of Ammonia reformer, and is considered Iran's first CCU plant

CDR project at Kermanshah Petrochemical Industrial Complex (KPIC)

Upon successful start-up and operation of CDR plant at Besat Power Company, SCD Corporation was requested to prepare a proposal for a CO_2 recovery plant for KPIC, an Urea fertilizer petrochemical plant located in South Western Iran, in an effort to boost production and to eventually eliminate the need to store excess ammonia which is the normal activity in an Urea production facility.

The project was seen on an EPC basis from the very beginning with KPIC executing its own inspection according to highest engineering codes inclusive of API stiff standards, specifically when it came to rotary equipment such as blower and pumps. All equipment were fabricated in Iran using standards such as API, ASME and etc. The process to qualify vendors was rigorous, and only vendors on approved vendor list from Iran's National Petrochemical Company (NPC), were used in the process.

The timeline drafted originally by SCD spanned over 18 months from start to finish, which included training and start-up. However, with scope creeping and other unexpected delays, caused the project to be finished in 22 months. The CDR plant at KPIC recovers 132 MTPD from the stack of Ammonia reformer, and is considered Iran's first CCU plant. The CO_2 is utilized to boost Urea Production by as much as 5.5%. The 19th of June 2017 marked 2 years of continuous operation – in excess of 16000 operating hours- of the plant with reliability factor of 99.6%. As a result of this project, 40,000 tpa of CO_2 emissions have been avoided, while increasing the profitability of the plant at very minimal marginal cost.

SCD's costs structure both on CAPEX & OPEX fronts are considerably lower than foreign competition. This is due to the fact that almost everything is built within Iran, and thus, the savings from energy, labour and materials are considerable. SCD Corporation guarantees delivery of its unique solvent to the client once the license agreement is signed at a fraction it costs in comparison with available commercialized solvents. CDR technology offered by SCD carries an automatic two years warranty including spare parts in the scope of supply at no extra charge.

Many European countries such as Germany, France and Norway are conducting research activities for the development of post-combustion carbon capturing technology, and while these activities have not yielded to any commercializable technologies, SCD Corporation is proudly the new player on the world stage. Having licensed, designed and built two immensely successful PCC projects in Iran, the company is looking to expand its market reach beyond Iran's borders, thus it is actively looking to export the unique CDR technology.

More information

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Carbon capture and storage readiness index review of progress

This paper outlines the results of the Global CCS Institute's CCS Readiness Index and gives a comparative review of global progress towards wide-scale deployment.

By Christopher P. Consoli, Ian Havercroft, Lawrence Irlam

Carbon capture and storage (CCS) is critical for meeting international climate change targets and deployment must therefore be both rapid and global. To date, deployment has been limited to only a few countries with several factors slowing progress. These factors can be quantified to track a country's development and to identify enabling opportunities for wide-scale commercial deployment of CCS.

This paper outlines the results of the Global CCS Institute's CCS Readiness Index. The CCS Index quantifies these factors through a set of criteria across four indicators - inherent interest, policy, legal and regulatory, and storage - which are major barriers or accelerators to the deployment of CCS and compares results for over 30 countries. The methodology behind all three indicators is similar, with each indicator employing its own set of criteria to assess conditions within a country at a particular point in time. Countries are then scored against the criteria with the premise being that the highest scoring jurisdictions have the best opportunity for the deployment of a CCS project.

The CCS Index demonstrates that countries with clear, long-term policy commitments to use CCS technologies as an emissions reduction method rank highly. Despite strong development trends in some regions of the world, the majority of countries cluster around the midpoint of the analysis, suggesting some progress towards enabling CCS development, but not yet enough to encourage wide-scale deployment.

Methodology

A country's position within the CCS Index is based on final scores across the four indicators: interest, legal, policy, and storage. The four indicators each comprise a set of criteria which are used to individually score each nation. For the detailed methodology, including the criteria used in each indicator, the reader is referred to the Global CCS Institute. A summary of each of the indicators is outlined below:

• **Storage**: Utilises criteria that take into account all geological and technical aspects that could impact an injection and storage project within the borders of a country, including the geology, the maturity of storage assessments, site characterisation development and technical ability to store CO2.

• **Legal**: Criteria used offer a detailed examination and assessment of a country's national legal and regulatory frameworks, which are critical to the regulation of CCS. These may include environmental assessments, public consultation and long-term-liability.

• **Policy**: Criteria are based on an extensive range of policy measures that governments at all levels can use and are critical to CCS. This includes direct support for CCS as well as broader implicit support through measures such as carbon pricing and research funding for example.

• **Interest**: Set of criteria based on global shares of fossil fuel production and consumption.

The final country scores awarded in each of the four individual indicators were normalized (to 100), to enable an effective comparison within the CCS Index. It must also be noted that this report is an amalgamation of four indicators published in 2015 and as such, represents a snapshot of that year alone.

Notwithstanding these results, it should be acknowledged that a country's score within the indicators may change dramatically, particularly in the policy and regulatory space. The comparative assessment is therefore designed to be updated regularly in order to track the progress of each of these 30 countries as CCS deployment progresses.

This paper does not present an exhaustive examination of each country's results, but instead aims to provide a broad overview of the trends identified.

Results

The CCS Index reflects the current state of the CCS industry after approximately two decades of progress developing CCS as a low emissions technology. The storage indicator has an overall higher score when compared to the legal and policy indicators; the latter cumulatively scores the lowest. Within the interest indicator results, the correlation between a need to deploy CCS does not always result in higher scores across the other indicators.

Storage Indicator

The storage component of the CCS Index has a higher score on average than the other indicators. High scoring countries generally have favorable geology for storage, such as the Northwest Shelf of Australia, North Sea for Norway or the Cambrian Sands of Canada. These countries also have an advanced, mature petroleum industry or CO2-EOR operations, including Brazil, the Netherlands, UAE, UK, and US. All high scoring nations, apart from UAE have publically published national assessments for their storage potential, with most subsequently advancing to storage site assessments. Importantly, all but the UK have completed an injection project.

Most of the countries with moderate scores have not implemented a large-scale (>1 million tonnes) or commercial storage project. The absence of a project, together with a mix of immature or sporadic hydrocarbon field development (inherently linked to presence of subsurface data) and less favorable geological storage potential, has resulted in moderate scores. For nations with lower scores, there is not an individual criterion which has not been addressed, but a combination of factors which have impacted storage.

Most prominently, these lower-scoring countries have not completed detailed geological storage assessments and typically have no experience in completing an injection project at any-scale. Fig. 1 shows the comparison between the storage and interest indicators. Importantly the majority of the countries with high scores also score highly in their interest indicator, with a few critical exceptions in India, Indonesia, Malaysia and Russia.

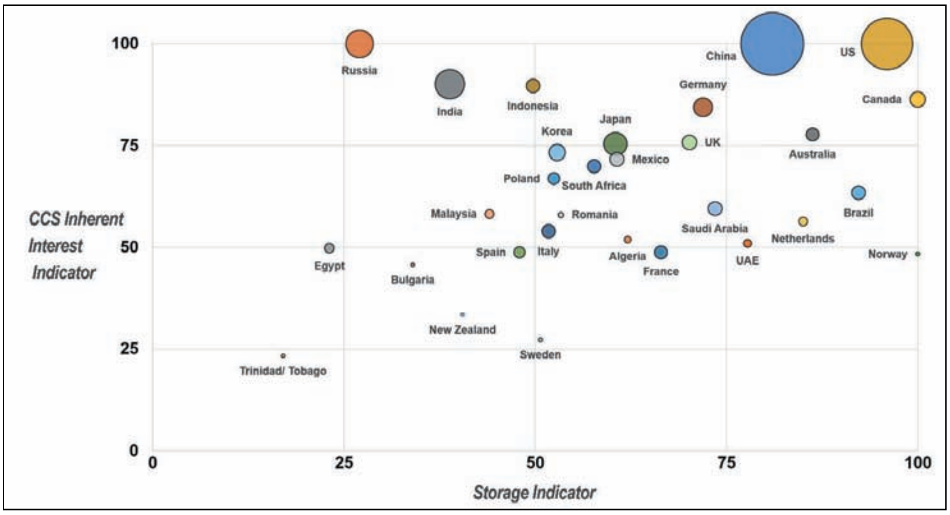


Fig. 1. Comparison between the storage and interest indicators. Bubble size reflects the total emissions according to the World Resources Institute 2010 data

Legal Indicator

The majority of countries received moderate scores under the legal and regulatory indicator, which reflects the present level of progress in the development of CCS laws and regulations globally. Only four countries score particularly highly. These countries, Australia, Canada, UK and US have been historically recognized as champions of the development of effective and comprehensive legal frameworks for CCS. These nations have developed detailed CCS-specific laws or have existing laws that are applicable across most parts of the CCS project cycle.

Despite this progress, there are no countries that have a regime that comprehensively addresses all of the core elements of a legal and regulatory model for the technology. Accordingly, there are no countries with an exceptionally high score (90+) as seen in the storage assessment. The four countries listed previously, as well as some of those with more moderate scores, have relatively comprehensive frameworks that can address legal and regulatory aspects across most of the CCS technology chain. Some countries have made amendments to existing resource legislation to regulate CCS activities, which indicates that mature industrialized countries, with an established oil and gas industry, may have a distinct advantage in CCS development.

Countries with low to moderate scores have far fewer CCS-specific laws and, in some instances, have prohibited CO2 storage activities in their territory. When comparing the legal indicator results to the inherent interest and emissions profile of nations, there is a clear trend that the majority of countries do not yet have adequate legal and regulatory frameworks across the entire CCS technology chain to support CCS development in their nations.

Policy Indicator

The majority of countries in the policy indicator have low scores. This finding is unsurprising as CCS does not receive equal policy support when compared to greenhouse gas mitigation technologies such as renewable electricity generation; supporting policy is the key enabler for the development of CCS. Countries with higher scores (Canada, Netherlands, Norway, UK and US) have long-term, clear and targeted support for CCS as a specific greenhouse gas mitigation technology.

The UK dropped in ranking between 2015 and 2016 as a result of the cancellation of its CCS Commercialisation Programme. Notwithstanding this, it still has various policies that can act to encourage CCS, in the form of emission performance standards and a carbon price floor, as well as supportive institutions. Hence, the policies of the UK still enable a high score relative to most nations. The UK Government's stance on CCS in the absence of large-scale funding is expected to become clearer by early 2017.

Countries that rank highly within the policy indicator have employed a broad range of measures to pursue climate change targets. Governments in these countries have also made consistent statements that identify the important role of CCS alongside other low and zero emission technologies. Investment in CCS projects and research is supported via a combination of legislated requirements, market based incentives and supportive institutional arrangements.

Countries with higher rankings have direct regulation of emissions from power plants, thus encouraging the deployment of CCS in this sector. Subsequently, aside from the UK, most of the nations that rank highly against the policy indicator have an operational large scale CCS project.

Countries that score moderately have fewer direct policies with regard to the role of CCS in overall climate change policy. Some of these countries have CCS projects in the operational stage, but without significant direct subsidies, rely upon enhanced oil recovery using CO2 (CO2-EOR) to make the projects commercially viable.

Countries with lower scores have not developed clear policies on the role of CCS as a specific greenhouse gas mitigation technology. Despite a significant proportion of countries scoring moderately, in the overall comparative assessment, nations such as Australia, China and Japan are making significant progress.

Compared to the legal and storage indicators, the majority of nations in the policy assessment receive lower scores. Countries in this category have relatively less stringent climate change targets than higher scoring nations or are at earlier stages of economic development. Accordingly, CCS may be considered to be less of a priority in the short term. Brazil, Indonesia, Mexico and Poland, Saudi Arabia, UAE have demonstrated an interest in pursuing CCS in achieving climate change objectives, but generally also observe CCS primarily for EOR. Some of these nations do have CCS demonstration and pilot projects, which suggest that a CCS project can still be developed.

Discussion

Key Findings

The results of the CCS Index show that nations with a long-term (decadal), strategic approach to CCS as a low-emission technology for its climate change emission reduction goals, score high across the policy, legal and storage indicators. These nations include Australia, Canada, the Netherlands, Norway, UK and the US. When compared to the interest indicator, all but the Netherlands and Norway all score highly.

This demonstrates that nations that are high consumers and/producers of fossil fuels have long acknowledged the role CCS will play in emissions reduction for climate change objectives. The same group of high-scoring nations, again with the exception of the Netherlands and Norway, are also major emitters. In contrast, there are nations that are both high scoring in terms of CCS interest and emissions, but do not score highly across all indicators. These countries include China, Germany, Japan, India, Korea and Russia.

High scoring nations have largely developed a long-term strategic approach to the technology and have a cohesive and holistic framework around CCS. Lower-scoring nations, conversely, have adopted an ad-hoc or sporadic approach to the inclusion of CCS in their domestic emission reduction targets. Among some of the lower scoring countries, certain nations score highly in storage (for example China and Germany), but those same nations do not have, publically at least, clear and targeted support for CCS as a specific greenhouse gas mitigation technology.

Nations such as Canada and Australia have clearly identified a need for CCS and have policies supportive of CCS across many key government platforms (direct regulation, CCS funding agreements etc.), whilst collectively developing their CO2 storage potential and legal and regulatory frameworks to enable a CCS project. Subsequently, Canada and Australia have CCS projects operating (Quest CCS Project, Canada) or under construction (Gorgon CO2 Injection Project, Australia) that will capture and store CO2 from industrial processes specifically for emission reduction.

A further important observation from the CCS Index is the fact that that no country possesses a perfect score. Storage results, when contrasted with those from the policy and legal indicators, sees countries score higher overall despite several areas of potential improvement. The large majority of countries score moderate to low in the legal indicator and low in the policy indicator, which is perhaps indicative of the previous assumption that technological development always leads policy and regulatory development. This assumption reflects the desire of policy makers to examine the technical feasibility of a technology, in this case the capture, transport, storage of CO2 prior to implementing policies and legislation to support fuller deployment of CCS.

Key Implications

The CCS Index provides a detailed perspective of the current status of CCS in 2015. The findings reveal four main implications based on the countries' results within the four indicators:

1. Long-term, cohesive and clear policies, in concert with the development of storage sites and regulatory frameworks across the entire CCS technology chain, creates an enabling environment for investment of CCS in a country.

2. High-scoring nations have developed their CCS industry over at least two decades. This has included the development of policy commitments, legislative development, and storage characterisation and testing across government at all levels, as well as industry engagement and applied research.

3. The legal, policy and storage indicators provide a point-in-time assessment of a country's strengths and weaknesses in seeking investment for CCS deployment and can highlight individual barriers and opportunities through the criteria-based approach.

4. If the emission reduction goals and climate change objectives of the majority of the 30 nations reviewed in the CCS Index are to be achieved, addressing of individual criteria to create an enabling environment for CCS investment needs to be expedited globally.

The lower scores of the policy and legal indicators actually present significant opportunities. Specifically, countries could readily create an enabling environment with particular policy or legal developments by addressing particular low scoring criteria within the indicators. Japan, for example, received a low regulatory assessment score for its current regulatory frameworks for offshore storage, however the government is actively addressing many of the remaining barriers and according to Gibbs [13] is developing its regulatory framework for CCS.

The Global CCS Institute, highlights that worldwide there are presently 22 large-scale projects, 16 of which are associated with CO2-EOR. The capture of anthropogenic CO2 from industrial sources and power stations with storage has mainly been commercially viable because of the revenue from the increase in production of oil. However, the six remaining large-scale projects - which are operational or under-construction - are not CO2-EOR projects and are directly related to emissions reduction.

The commercial driver for all of these projects was regulation, either through direct emissions reduction requirements or regulation such as a price on carbon dioxide. Unsurprisingly, of the six high scoring nations of the CCS Index (Australia, Canada, the Netherlands, Norway, UK and the US), five have CCS projects without CO2-EOR. This shows that creating an enabling environment through regulation and policy development, in concert with the appraisal and development of storage sites does result in investment of CCS as an emission reduction technology.

Summary

The overall premise of the CCS Index is that a high score across the storage, legal and policy indicators, especially for those nations with a high CCS interest will create an enabling environment for investment in the wide-scale, commercial deployment of CCS.

These indicators are based on criteria that are barriers or accelerators for CCS. The obvious lack of high scoring countries is reflective of the overall CCS policy environment in 2015, but there are a few leading nations, which show that a long term strategic approach in addressing those criteria can lead to the deployment of CCS for emission reduction targets.

More information

Download the fully referenced paper from:

www.globalccsinstitute.com

Projects and policy news

Vattenfall power plant evaluated for hydrogen+CCS

www.vattenfall.com

Vattenfall's gas power plant Magnum will be evaluated for hydrogen production and CCS (Photo: Koos Boertjens / Vattenfall)

Statoil, Vattenfall and Gasunie have signed a Memorandum of Understanding (MoU) to evaluate the possibilities of converting Vattenfall's gas power plant Magnum in the Netherlands into a hydrogen-powered plant.

The next steps will involve feasibility studies to evaluate the conversion of one of the three Magnum units of Vattenfall Nuon in Eemshaven to run on hydrogen. The units are operated by the company's Dutch subsidiary. In addition, Gasunie examines which infrastructure for transport and storage is needed.

The scope of the MoU also includes exploring how to design a large-scale value chain where production of hydrogen is combined with CO2 capture, transport and permanent storage as well as considering potential business models.

"We are very excited about getting the opportunity to evaluate the possibilities of converting a gas power plant in to run on hydrogen. We are still in an early phase and like all pioneer projects there are uncertainties that need to be addressed. But the potential CO2 emission reduction is significant", says Irene Rummelhoff, executive vice president for New Energy Solutions in Statoil.

The Magnum gas power plant has three combined cycle gas turbines (CCGT) with a capacity of 440 MW each. One CCGT emits approximately 1.3 million tons of CO2 per year.

Designing a large-scale value chain

The technology for producing hydrogen by converting natural gas into hydrogen and CO2 is proven and known. The new element is to design a large-scale value chain.

"Designing a large-scale value chain where production of hydrogen from natural gas is combined with CO2 capture, transport and storage can open up new business opportunities", says Rummelhoff.

So far, high costs combined with lack of CO2 storage facilities have limited the development of a low-carbon value chain for hydrogen based on natural gas.

In 2016, the Norwegian government initiated a new national CO2 capture, transport and storage project. Studies confirmed the feasibility of storing CO2 on the Norwegian continental shelf, with high storage capacity and the potential to expand the facilities to manage additional CO2 volumes beyond the initial demonstration project.

If the Norwegian CCS demonstration project is realized, this may open up for future CO2 storage from other projects, including the joint Vattenfall, Gasunie and Statoil project.

Indian Oil and LanzaTech to build gas to bioethanol refinery

www.lanzatech.com

Indian Oil Corporation Limited and LanzaTech ave signed a Statement of Intent to construct the world's first refinery off gas-to-bioethanol production facility in India.

LanzaTech has developed a gas fermentation process to make fuels and chemicals. Instead of sugars and yeast, the company uses a biological catalyst to ferment waste gas emissions. The large volume of waste gas produced at industrial facilities such as refineries cannot be stored or transported; rather it must be combusted to make power locally and emitted as carbon dioxide (CO2). Power can be carbon-free, and in India today, the cost of renewable power has fallen below the cost of coal, accelerating the transition to a carbon-free grid. LanzaTech's technology allows refineries to divert waste gases from the grid, supporting the transition to fully renewable power while recycling this carbon into liquid fuels and petrochemicals.

India is adopting a cleaner and greener economic growth pathway today, with the Government running one of the largest renewable capacity expansion programmes in the world. The implementation of the National Smart Grid Mission, along with new programmes for increasing energy capacities from wind and waste conversion, are key elements of this vision. This vision is inextricably linked to the principle of 'need-based consumption' which follows the need to maximise on existing resources and decarbonise everyday activities.

For liquid fuels, this is highlighted by targets initiated by the Ministry of Petroleum & Natural Gas to increase the supply of ethanol-blended petrol (E10) to all parts of the country. IndianOil is aligned with this Ministerial vision and is working to both reduce its overall emissions and to improve refinery yields. For this reason, IndianOil has selected the LanzaTech technology which enables the beneficial reuse of carbon-rich off-gases for the production of ethanol. The ethanol produced from the recycling of refinery off-gases is expected to have a greenhouse gas emissions savings of over 70 per cent compared to conventional gasoline.

The basic engineering for the 40 million litres (35K MTA) per annum demonstration facility will begin later this year for installation at IndianOil's Panipat Refinery in Hayrana, India, at an estimated cost of 350 crore rupees (USD 55 million). It will be integrated into existing site infrastructure and will be LanzaTech's first project capturing refinery off-gases. LanzaTech's first commercial facility converting waste emissions from steel production to ethanol will come online in China in late 2017.

"India is on track to exceed its Paris commitments," said India's Minister of Petroleum and Natural Gas, Mr. Dharmendra Pradhan. "This is thanks to investment in novel low-carbon technologies such as this project between IndianOil and LanzaTech. It is promising to see carbon turned from a liability into an opportunity, where we can reduce emissions, maximise resources and decarbonise our economy."

"Innovation is one of IndianOil's core values as evidenced by our continued investment in our R&D and engineering teams," said Mr. Sanjiv Singh, Chairman IndianOil. "Innovation helps us learn and grow and this project at the Panipat Refinery enables us to continue to move forward with our commitment to build a strong sustainable business that demonstrates concern for society and the environment. The biofuels we will be able to produce will support the requirements for motor spirit blends set by the Government of India while enabling IndianOil to add value while reducing its emissions."

"India is leading a transformational shift which balances industrial growth with the needs of society and the environment," said Dr Jennifer Holmgren, CEO of LanzaTech. "Changes in the energy paradigm pose a serious challenge for energy companies but IndianOil is taking the challenge as an opportunity.

They are leading the next generation of refiners as they diversify India's energy sources and explore alternative ways to meet the country's energy needs, sustain economic growth and alleviate energy poverty. We are very proud to be working with IndianOil as it plans the first deployment of LanzaTech technology in one of its major refineries, demonstrating the broad applicability of emissions recycling across industrial sectors, beyond steel."

The potential impact of using off-gases from the refining sector in India is considerable. India would be able to produce 40-50 KMTA of ethanol per refinery while saving about 1 million tonnes of CO2 per annum. This is the equivalent emissions savings as taking 850,000 cars off the road in India each year.

FuelCell Energy works with NRG Energy Center on project

www.fuelcellenergy.com

The NRG Energy Center in Pittsburgh, Pennsylvania, owned by NRG Yield, will host a fuel cell power plant under a previously awarded U.S. Department of Energy contract.

The power plant will deliver energy to the NRG Yield facility, which provides heating and cooling for more than six million square feet of commercial and residential facilities in downtown Pittsburgh. NRG Energy Center Pittsburgh is owned by NRG Yield.

According to NRG Energy Center Pittsburgh General Manager Cliff Blashford, "This project supports NRG Yield's focus on identifying and integrating energy solutions that seek to improve efficiency, lower fuel consumption and costs, and reduce our environmental footprint. We're pleased to participate, and to support Mayor Peduto's vision of a smarter, cleaner and more innovative energy future for Pittsburgh."

"We are leveraging our commercial experience with this new solution, including industry leading electrical efficiency plus thermal capabilities packaged in a design that installs quickly," said Chip Bottone, President and Chief Executive Officer, FuelCell Energy.

"While this application in Pittsburgh will be a demonstration of the use of our solid oxide fuel cell platform for efficient power generation, this common cell platform is also being used in other programs as the basis for our energy storage technology, whereby the cells alternate between electrolysis and fuel cell operation, producing hydrogen during electrolysis mode which is later used to make power in fuel cell mode."

FuelCell Energy's SOFC power generation technology generates industry-leading electrical efficiency of approximately 60 percent plus usable heat for combined heat and power applications, resulting in total estimated thermal efficiency between 80 and 85 percent. The fuel cell plant hosted at the NRG facility will operate solely on clean natural gas, although the technology is fuel flexible, with the ability to utilize coal syngas, natural gas, on-site renewable biogas or directed biogas. Fuel cells electrochemically convert a fuel source into electricity and heat in a highly efficient process that emits virtually no pollutants due to the absence of combustion.

Inventys raises CAD$10M

www.inventysinc.com

The financing supports the deployment of a next-gen carbon capture pilot plant at Husky's Pikes Peak South Lloyd thermal project.

Husky Energy is the lead investor. The Company raised total cash proceeds of CAD$10 million in this first tranche of its current Round B-11 financing process, including investments from existing investors, The Roda Group and Chrysalix Energy Venture Capital.

Proceeds from the transaction will fund a 30-tonne per day (TPD) CO2-capture pilot plant aimed at producing a low-cost CO2-supply solution for Husky's heavy oil enhanced oil recovery (EOR) program near Lloydminster, Saskatchewan.

"We're very pleased to work with Husky and welcome its investment and industry knowledge," said Inventys President and Chief Executive Officer, Claude Letourneau. "This is the world's first pilot-scale plant using structured adsorbents to capture CO2 from a once-through steam generator (OTSG) for use in heavy oil recovery."

Letourneau added, "Canada offers the perfect setting to prove our second generation carbon capture technology, reduce carbon emissions, uphold Canada's climate goals, create jobs, and support industrial growth."

Earlier this year, Inventys commissioned a self-contained 0.5 TPD VeloxoTherm field demonstration plant at the same Husky site as a platform for rapid development of its new adsorbent structures. The demo plant has recorded meaningful data since testing began in early 2017. The test results over the next six months will shape the design of the 30-TPD plant. The pilot plant is planned to be commissioned in the fall of 2018.

Photo-activated catalyst grabs CO2 to make ingredients for fuel

Scientists at Berkeley Lab have developed a light-activated material that can chemically convert carbon dioxide into carbon monoxide without generating unwanted byproducts.

The achievement marks a significant step forward in developing technology that could help generate fuel and other energy-rich products using a solar-powered catalyst while mitigating levels of a potent greenhouse gas.

When exposed to visible light, the material, a "spongy" nickel organic crystalline structure, converted the carbon dioxide (CO2) in a reaction chamber exclusively into carbon monoxide (CO) gas, which can be further turned into liquid fuels, solvents, and other useful products.

An international research team led by scientists at the Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) and Nanyang Technological University (NTU) in Singapore published the work July 28 in the journal Science Advances.

"We show a near 100 percent selectivity of CO production, with no detection of competing gas products like hydrogen or methane," said Haimei Zheng, staff scientist in Berkeley Lab's Materials Sciences Division and co-corresponding author of the study. "That's a big deal. In carbon dioxide reduction, you want to come away with one product, not a mix of different things."

Berkeley Lab scientists Kaiyang Niu (left) and Haimei Zheng, principal investigator, developed a new photocatalyst of metal organic composites that can effectively convert carbon dioxide into the ingredients for fuel. They made the new material, held by Zheng in a glass vial, by exposing a precursor solution to laser irradiation. (Credit: Marilyn Chung/Berkeley Lab)

Getting rid of the competition

In chemistry, reduction refers to the gain of electrons in a reaction, while oxidation is when an atom loses electrons. Among the well-known examples of carbon dioxide reduction is in photosynthesis, when plants transfer electrons from water to carbon dioxide while creating carbohydrates and oxygen.

Carbon dioxide reduction needs catalysts to help break the molecule's stable bonds. Interest in developing catalysts for solar-powered reduction of carbon dioxide to generate fuels has increased with the rapid consumption of fossil fuels over the past century, and with the desire for renewable sources of energy.

Researchers have been particularly keen on eliminating competing chemical reactions in the reduction of carbon dioxide.

"Complete suppression of the competing hydrogen evolution during a photocatalytic CO2-to-CO conversion had not been achieved before our work," said Zheng.

At Berkeley Lab, Zheng and her colleagues developed an innovative laser chemical method of creating a metal-organic composite material. They dissolved nickel precursors in a solution of triethylene glycol and exposed the solution to an unfocused infrared laser, which set off a chain reaction in the solution as the metal absorbed the light. The resulting reaction formed metal-organic composites that were then separated from the solution.

"When we changed the wavelength of the laser, we would get different composites," said study co-lead author Kaiyang Niu, a materials scientist in Zheng's lab. "That's how we determined that the reactions were light-activated rather than heat-activated."

The researchers characterized the structure of the material at the Molecular Foundry, a DOE Office of Science User Facility at Berkeley Lab. The nickel-organic photocatalyst had notable similarities to metal-organic frameworks, or MOFs. While MOFs have a regular crystalline structure with rigid linkers between the organic and inorganic components, this new photocatalyst incorporates a mix of soft linkers of varying lengths connected with nickel, creating defects in the architecture.

"The resulting defects are intentional, creating more pores and sites where catalytic reactions can occur," said Niu. "This new material is more active and highly selective compared with MOFs made by traditional heating."

Reducing CO2 to CO

Scientists at NTU tested the new material in a gas chamber filled with carbon dioxide, measuring the reaction products using gas chromatography and mass spectrometry techniques at regular time intervals. They determined that in an hour at room temperature, 1 gram of the nickel-organic catalyst was able to produce 16,000 micromoles, or 400 milliliters, of carbon monoxide. Moreover, they determined that the catalyst had a promising level of stability that allowed it to be used for an extended time.

The reduction of carbon dioxide by catalysts is not new, but other materials typically generate multiple chemicals in the process. The near-total production of carbon monoxide with this material represented a new level of selectivity and control, the researchers emphasized.

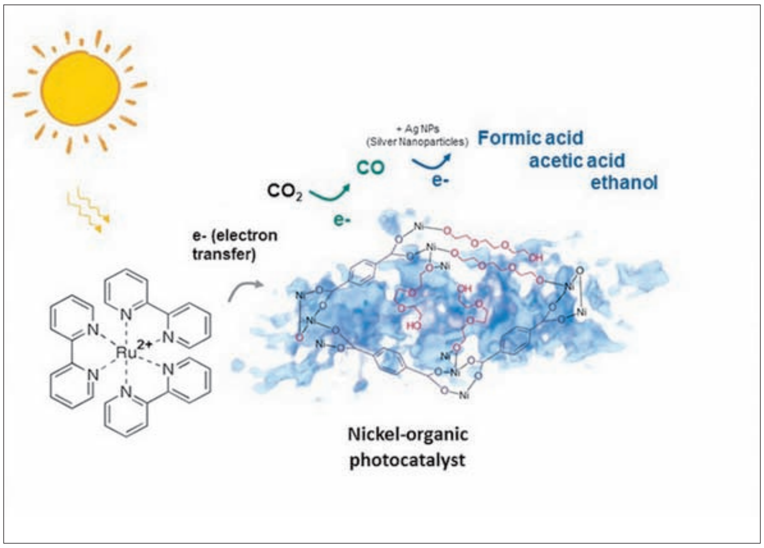
The researchers have some thoughts about how this selectivity occurs. They suggest that the architecture of their photocatalyst makes it easier for carbon dioxide anions to bind to reaction sites, leaving little space for hydrogen radicals to land. This would limit the proton transfers necessary to form hydrogen gas, the researchers said.

The researchers pushed the nickel-organic photocatalyst further by enriching it with rhodium or silver nanocrystals to create formic and acetic acids, respectively. Formic acid, found in ant venom and stinging nettles, and acetic acid, the main component of vinegar, are both used widely in industry. More importantly, the researchers noted, the molecules of these products are characterized by two-carbon links, a step toward the generation of higher-energy liquid fuels with more carbon bonds

"The world right now is in need of innovative ways to create alternatives to fossil fuels, and to stem the levels of excessive CO2 in the atmosphere," said Zheng. "Converting CO2 to fuels using solar energy is a global research endeavor. The spongy nickel-organic photocatalyst we demonstrated here is a critical step toward practical production of high-value multi-carbon fuels using solar energy."

Other authors on this paper include co-corresponding author Rong Xu, NTU associate professor of chemical and biomedical engineering; You Xu, NTU research fellow in Xu's lab; visiting scholar Haicheng Wang and scientist Joel Ager at Berkeley Lab's Materials Sciences Division; and Karen Bustillo, a scientific engineer at the Molecular Foundry.

The DOE Office of Science supported this work. Additional characterization work was done at the Center for Functional Nanomaterials at Brookhaven National Laboratory, also a DOE Office of Science User Facility.



Schematic of a spongy nickel-organic photocatalyst converting carbon dioxide exclusively into carbon monoxide, which can further be converted to high-value liquid fuel through visible light-induced photocatalysis. (Credit: Kaiyang Niu and Haimei Zheng/Berkeley Lab)

More information

www.lbl.gov

Capture and utilisation news

Econic Technologies develops tunable catalyst for CO2 conversion

www.econic-technologies.com

The catalyst, developed by a team of British scientists, converts CO2 into polyols, a key building block in polyurethane plastics.

With a global market valued in excess of £15 billion, polyols are the key building blocks in polyurethane, which is used to make automobiles, bedding, furniture, footwear and other household and industrial products.

Econic Technologies' new tunable catalyst now enables polyol manufacturers to incorporate bespoke amounts of captured CO2 emissions into these polyol chains during the manufacturing process. The amount of CO2 can be dialled up or down depending on the performance requirements of the application.

The tunable catalyst means that CO2 can be incorporated at low pressures via equipment that is retrofitted easily and economically to existing production plants. By allowing for a reduction of oil-based feedstocks, the catalyst could save a typical production unit with an output of 50kte/annum in excess of £36 million per year.

What's more, not only does the catalyst enable manufacturers to use their own carbon dioxide emissions as a raw material, but by reducing quantities of environmentally demanding, oil-based inputs, it further lowers emissions.

Dr Rowena Sellens, CEO of Econic Technologies, commented on the launch, "As the tunable catalyst moves out the lab and into mainstream use, we are aiming to work with our customers to totally transform polyurethane manufacturing: making it greener, cheaper and safer."

Founded in 2011 by Charlotte Williams, now Professor of Catalysis and Materials Chemistry at the University of Oxford, Econic Technologies pioneers catalyst technologies for application within the plastics industry. The team of 26 includes more than 20 scientists and engineers. The underlying catalyst technology was developed at Imperial College London.

Econic Technologies' catalyst allows companies to incorporate tunable amounts of CO2 into the production of polyols, a key plastic feedstock chemical

Ancient biology meets modern ingenuity

www.aibn.uq.edu.au

The University of Queensland and LanzaTech are studying bacteria that can capture CO2.

Researchers at The University of Queensland's Australian Institute for Bioengineering and Nanotechnology (AIBN) and US company LanzaTech have developed a computer model that harnesses ancient microorganisms for an environmentally sound industrial waste conversion method.

AIBN researcher Dr Esteban Marcellin said LanzaTech, a gas fermentation company, was particularly interested in a bacterium called Clostridium autoethanogenum, originally discovered in rabbit droppings.

"LanzaTech uses this bacterium (which falls under the broader class of acetogens) as part of its carbon capture and reuse process, whereby industrial waste gases such as steel mill exhaust are converted into useful by-products like ethanol," Dr Marcellin said.

"Acetogens are among the oldest living microorganisms and account for around 20 per cent of the fixed carbon on the planet, making them a major player in the global carbon cycle."

Through an Australian Research Council linkage project, LanzaTech teamed up with AIBN researchers to better understand the process by which the microbe 'fixes' carbon monoxide and carbon dioxide, and then determine how to modify the microbe so that waste gas can be turned into useful chemicals.

To achieve this LanzaTech researchers and Dr Marcellin's team developed a computer model of C. autoethanogenum's metabolic pathways.

LanzaTech founder and chief science officer Dr Sean Simpson said: "By including operating data from fermentations happening at steel mills around the world, the UQ team has made the most accurate model system published to date.

"The computer model is able to predict cellular metabolism of the microbe, which helps identify the best way to modify the organism so it can capture greenhouse gases better and convert carbon into desired products."

Lanzatech's director of synthetic biology Dr Michael Koepke said the model allowed scientists to predict what happened if certain genes were removed or overexpressed, or if an entirely new pathway was introduced.

"This opens the door to establishing acetogens as catalysts that can convert a variety of carbon-containing inputs into new products," Dr Koepke said.

The next step was to use the computer model to identify and modify gene targets in C. autoethanogenum, and then test the outcome at AIBN's gas fermentation facility, one of few non-industry facilities using instrumented fermenters and mass spectrometers for accurate gas data analysis.

The world-leading facility also boasts support infrastructure, which includes theoretical and computational science, and facilities that underpin capabilities in proteomics, metabolomics, biologics, stem cells, nanofabrication, and microscopy and microanalysis.

AIBN Director Professor Alan Rowan said that industrial biotechnology was one of the institute's key future research pillars and would "become the next industrial revolution playing a critical role in Queensland's future economy and that of Australia.'

Research underpinning the AIBN and LanzaTech collaboration has been published in the journal Cell Systems.

New membranes help reduce CO2 emissions

www.utwente.nl

The University of Twente and the German research centre Jülich are collaborating on developing membranes for an efficient separation of gases, to use for the production of oxygen or hydrogen.

The ceramic, ion-conducting membranes are an alternative for existing expensive separation processes and contribute to the reduction of CO2 emission. Prof. dr. Wilhelm Meulenberg, professor in Inorganic Membranes at the University of Twente, expects it to take about five to ten years before this latest technology is available. Meulenberg is also affiliated with the Jülich Research Centre.

In the coming decades, sustainable energy sources (sun, wind) and more efficient energy use are not sufficient for achieving the targeted mitigation of the greenhouse effect. In order to achieve the European climate goals, the collection and storage of CO2are required as well, and we are considering the efficient conversion of CO2 to fuel (Carbon Capture and Utilization CCU). It is expected that in this way, the CO2 emission in Europe up until 2030 can be reduced by 15%.

Existing techniques for capturing CO2, such as chemical washing (Water Wash) are costly and go hand in hand with a large loss of energy. The oxyfuel technology, in which fuels are burned with pure oxygen in a CO2 neutral process, is not a perfect solution either with our current technology levels, as the production of pure oxygen through distillation at –190°C takes a lot of energy.

Using membranes that are able to separate oxygen is a much better and more efficient alternative. This way, the fuel can still be burned with pure oxygen, producing a gas with a very high concentration of CO2. One of the other possibilities is the production of synthetic fuels, which develop through the reaction of CO2 with hydrogen across a membrane.

The University of Twente and Jülich Research Centre have decided to work closely together to develop ceramic ion-conducting membranes for this purpose. These membranes are intended for membrane reactors, which under extreme circumstances (high temperatures, high pressure) combine the separation process with a chemical reaction, which results in the production of synthetic fuels or basic chemicals.

DOE invests $4.8 million in projects to advance beneficial use of CO2

energy.gov/fossil

The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) has selected an additional five projects to receive $4.8 million to investigate novel uses of carbon dioxide captured from coal-fired power plants.

Each project will contribute a non-federal cost share of at least 20 percent, bringing the total award value of the projects to more than $6.1 million.

The five projects fall under three technical areas of interest:

Area of Interest 1: Biological-Based Concepts for Beneficial Use of CO2

A Combined Biological and Chemical Flue Gas Utilization System towards Carbon Dioxide Capture from Coal-Fired Power Plants

Michigan State University will develop a combined biological and chemical system to sequester CO2 from coal-fired power plants in biological absorbents and generate value-added products. This approach is expected to significantly reduce the land and energy footprint of CO2 capture, as well as minimize capital and operational expenses.

Improving the Economic Viability of Biological Utilization of Coal Power Plant CO2 by Improved Algae Productivity and Integration with Wastewater Treatment

The University of Illinois will demonstrate significant improvements in the cost and environmental impact of utilizing CO2 from coal-fired power plants to grow algae biomass suitable for large-volume, value-added commodity markets.

Area of Interest 2: Mineralization Concepts Utilizing CO2 with Industrial Wastes

CO2 Mineralization Using Porous Carbon and Industrial Wastes to Make Multifunctional Concrete

Rice University will develop a new protocol integrating a collection of advanced synthesis and characterization techniques, a thorough combination of lab-simulation and pilot tests, as well as life-cycle analysis. Together these components will provide a system approach to achieving the most beneficial and cost-effective technology for use of CO2 in value-added, scalable products.

Storing CO2 in Built Infrastructure: CO2 Carbonation of Precast Concrete Products

The University of Michigan will advance the technical understanding of CO2 incorporation into novel cementitious materials for the development of high-value products that provide a net reduction in carbon emissions.

Area of Interest 3: Novel Physical and Chemical Processes for Beneficial Use of Carbon

Novel Catalytic Process Technology for Utilization of CO2 for Ethylene Oxide and Propylene Oxide Production

RTI International will develop and optimize a novel catalytic process for reacting CO2 with ethylene to produce ethylene oxide and carbon monoxide, both of which the commodity chemical industry uses for markets on the megaton scale.

Leaks will not sink carbon capture and storage

A Princeton University study shows CO2 storage would not be prone to significant leakage or high costs related to fixing leaks.

In a paper published July 26 in the journal Climatic Change, the researchers concluded that levels of leakage based on simulations at hypothetical subsurface carbon dioxide storage locations, even in a worst-case scenario, would not make the cost of the technology prohibitive in the global energy system.

In carbon capture and storage, carbon dioxide gas, which is released from burning oil and gas, is captured at a source such as a power plant. The gas is compressed into a dense fluid and injected a kilometer or more below the land surface for permanent storage. While the technology is not yet being used in large scale, advocates believe it is a promising strategy for climate change mitigation while fossil fuels are still being used. A chief worry, however, is whether the gas could leak and return to the atmosphere.

To reach their conclusion, the researchers mathematically simulated the geophysical impacts of carbon storage, which include projections of leaks, in combination with the economic impact of stopping leaks and paying associated fines and penalties.

Hang Deng, a former doctoral student at Princeton and the paper's lead author, explained that carbon capture and storage has been researched for years, with many studies focusing on the efficacy of the process and the potential for leakage. But the Princeton team wanted to understand both the level of leakage and the economic implications of any escaping gases.

"That link was not there before, and that is really what has motivated our study," said Deng, who graduated in 2015 and is now a postdoctoral researcher at Lawrence Berkeley National Laboratory. "I think this is really the first attempt trying to make this link and using the scientific findings (regarding geologic CO2 storage) to inform global climate change mitigation efforts."

Catherine Peters, an author and chair of Princeton's Department of Civil and Environmental Engineering, said the researchers wanted to answer two questions: Would the technology lead to significant leaks, and would the leaks have an economic impact on commercial adoption of the technology? The answer to both, she said, was no.

"Prior to this study, that question had not been answered," Peters said.

The study was done with modeling based on both the geophysical aspects of carbon capture and storage, such as flow through subsurface geological formations, and economic modeling of the global energy market, using an integrated assessment model.

"We studied the most worst-case scenarios," Peters said. "And even with the extreme worst-case scenarios, we still found that the CO2 will be reliably trapped underground when you put it there."

Deng said there were different types of impacts that were quantified. These included groundwater contamination and escape into the atmosphere. Another was the possibility that leaked CO2 may interfere with subsurface operations such as natural gas storage. In the modeling, however, the monetized risks of those impacts were negligible.

That finding is highly important for the future of climate change mitigation, Peters said. "For more than a decade, people have been pointing to leakage as a potential barrier for widespread adoption of carbon capture and storage," she said.

Deng's research was also unique in other ways.

"At Princeton, we are giving students a unique opportunity to conduct research that combines different fields," Peters said. "This is an unusual study in that we have a geophysics model and an economics model together."

That cross-disciplinary work is encouraged by Princeton's Program in Science, Technology and Environmental Policy (STEP), which is based in the Woodrow Wilson School of Public and International Affairs.

Deng, who was awarded a competitive STEP fellowship, chose to work with Peters on the engineering and geophysical modeling and with Michael Oppenheimer, the Albert G. Milbank Professor of Geosciences and International Affairs and the Princeton Environmental Institute, on the economic modeling and the policy analysis.

"It's because of that fellowship and this resourceful, industrious student that we were able to come up with this unique finding, because if you had studied just one or the other, we would not have learned what we learned," Peters said.

This type of study across multiple disciplines is becoming increasingly critical when it comes to solving thorny issues such as climate change, Peters said.

Besides Peters and Deng, authors include: Michael Oppenheimer, director of Princeton's Program in Science, Technology and Environmental Policy; Jeffrey M. Bielicki of the John Glenn College of Public Affairs and Department of Civil, Environmental and Geodetic Engineering at Ohio State University; and Jeffrey P. Fitts, of the Department of Civil and Environmental Engineering at Princeton.

Support for the project was provided in part by the Program in Science, Technology, and Environmental Policy at Princeton through the William Clay Ford, Jr. '79 and Lisa Vanderzee Ford '82 Graduate Fellowship fund, and National Science Foundation grants from the Chemical, Bioengineering, Environmental and Transport Systems Division and the Sustainable Energy Pathways program.

More information

www.princeton.edu/geosciences

Current status of global storage resources

Assessments that identify suitable sedimentary basins and their capacity are the first logical step in defining global carbon capture and storage potential. This paper presents a collation and summary of the current status of storage assessments worldwide known as the Global Storage Portfolio.

By Christopher P. Consoli, Neil Wildgust, Global CCS Institute

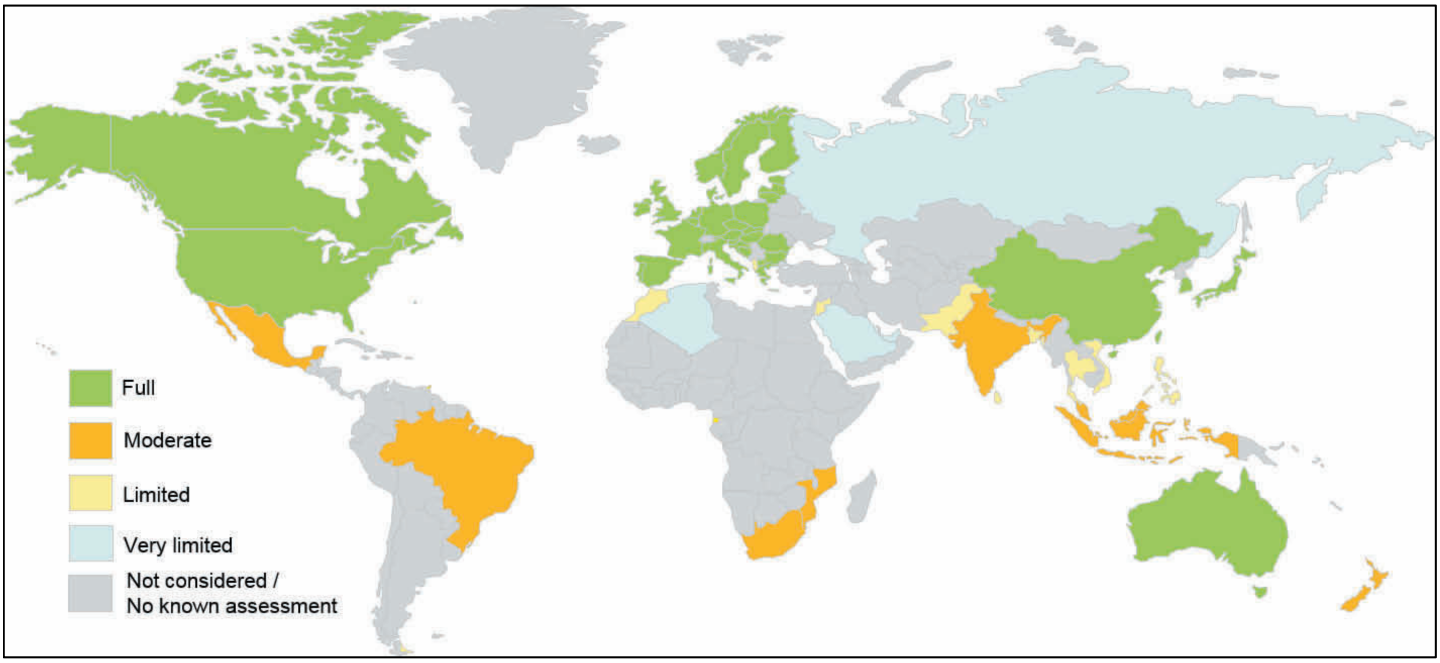


Fig. 1. Geographical coverage of the status of storage resource assessments. After Global CCS Institute Global Status of CCS 2015

The analysis found that there are substantial storage resources available in most regions of the world. Almost all nations that have published regional assessments have identified sufficient storage resources to support multiple carbon capture and storage projects. This analysis also found that the methods to determine and classify resources are highly variable across regions despite reliable assessment methodologies being available.

Methodology

The portfolio focuses on the storage resource of countries that have publically published assessments, where storage resource values are presented. It covered five regions, Asia-Pacific (14 countries), Americas (four countries), Middle East (three countries), EU and surrounds (EU plus three countries) and Africa (four countries). Multi-national or national-level assessments that calculated the storage resource using a single methodology was the main publication type.

The goal of the portfolio was to identify the storage potential for the future deployment of CCS. For this reason, only proven storage formations including deep saline formations (DSF), depleted/depleting oil and gas fields (DGOF) and enhanced oil recovery using CO2 (CO2-EOR) are considered. The term storage resource is used throughout this document. There is a crucial distinction between storage resource – which may be regarded as technically accessible storage space not allowing for economic, legal and regulatory factors – and storage capacity, which could be regarded as storage space proven with a higher degree of confidence, and allowing for non-technical factors.

There are three key factors surmised in the portfolio:

1. Estimated resource: published value calculated through typical volumetric calculations, the accuracy of which is defined by point's one and two below.

2. Status of assessment: categorises the specific details behind the resource assessment, ranging from a detailed national assessment identifying prospective basins and their storage resource ('full'), through to an international study based on large assumptions and sparse datasets ('limited').

3. Resource level: degree of detail that has gone into that estimated resource using the CSLF classification pyramid.

Results

A review of the results (Table 1) finds that the current published studies show there is vast storage resource potential when compared to the ambitious goals of the IEA. The majority of regional assessments used the CSLF calculation method or a method closely comparable. This method is a simple static volumetric calculation of the total pore space, followed by determining how much of the pore space can be physically accessed by CO2, using an efficiency factor.

Numerous other methods were used but most were still essentially static volumetric calculations. Moreover, some nations completed probabilistic calculations, resulting in a range of values for this storage resource (eg. US), whilst other nations published single values, such as the UK. Probabilistic calculations account for uncertainty in geological properties and subsurface conditions by using multiple ranges of values in the calculation. Deterministic calculations on the other hand uses single values, often the best estimate.

The majority of nations have not undertaken sufficiently detailed analysis (Fig. 1), with only nine nations completing 'full' assessments.

This suggests that most estimates presented in the portfolio do not take into account the full potential of the nation, most being limited to only oil and gas fields or specific basins. According the CLSF classification pyramid, the portfolio results show that most assessments have estimated their theoretical storage resource, with only eight nations estimating their effective storage resource. The theoretical resource is defined by the CSLF as the maximum storage potential of a storage area, whereas the effective resource is a subset of the theoretical, constrained by technical factors.

Based on these findings, it is important to state that each resource value should not be compared or collated to represent storage resource globally. This is largely because in each assessment the geological parameters, calculation method, quality of data and level of detail are different. Also that regional storage resource does not equate to proven storage capacity, which can only be obtained through detailed site-scale appraisal and includes engineering, economic, legal and regulatory factors.

Each of these factors affect the final amount of CO2 able to be injected and stored. Also, as research and storage exploration continues over time, the suitability of basins for storage will evolve along with the storage resources.

Country	Assessment status	Estimated resource (GT CO_2)	Resource level
ASIA-PACIFIC			
Australia	Full	227-702	Effective
Bangladesh	Limited	20	Theoretical
China	Full	1573	Effective
India	Moderate	47-143	Theoretical
Indonesia	Moderate	1.4-2	Effective
Japan	Full	146	Effective
Korea	Full	100	Theoretical
Malaysia	Moderate	28	Effective
New Zealand	Moderate	16	Theoretical
Pakistan	Limited	32	Theoretical
Philippines	Limited	23	Theoretical
Sri Lanka	Limited	6	Theoretical
Thailand	Limited	10	Theoretical
Vietnam	Limited	12	Theoretical
AMERICAS			
Brazil	Moderate	2,030	Theoretical
Canada	Full	198-671	Effective
Mexico	Moderate	100	Theoretical
USA	Full	2,367-21,200	Effective
MIDDLE EAST			
Jordan	Limited	9	Theoretical
Saudi Arabia	Very Limited	5-30	Theoretical
UAE	Very Limited	5-25	Theoretical
EUROPE AND RUSSIA			
Europe excluding UK	Full	72	Theoretical
Norway	Full	82	Effective
Russia	Very Limited	6.8	Theoretical
UK	Full	78	Theoretical
AFRICA			
Algeria	Very Limited	10	Theoretical
Morocco	Limited	0.6	Theoretical
Mozambique	Moderate	2.7-229	Theoretical
South Africa	Moderate	162	Theoretical

Table 1. Global Storage Portfolio Assessment Summary. Note: Each resource value was developed independently and should not be compared or collated to represent storage resource globally

Discussion

Accurate estimates of a region's storage capacity are a challenge, as each geological storage assessment will be inherently different. Regional assessments that estimate storage potential over wide geographical areas, for example multi-national surveys, are the first step to answering this challenge.

Regional assessments typically focus on the technical aspects of storage and can provide valuable information to policy makers, regulators and industry on the distribution and scale of the storage potential to support CCS deployment.

The main outcomes from regional assessments are an estimation of the storage resource, which is the potential storage space that could be utilised, subject to engineering, economic and regulatory factors. Two case studies represent how two regions have completed their storage assessments differently.

Europe

Europe (herein to include the European Union, the Balkans and Norway) were early movers on CO2 storage assessments. Europe has undertaken an almost classical systematic, 'bottom-up' approach to storage assessments for at least a decade. This has been led through government directives and through dedicated CCS programs and projects, which work openly in the scientific community having completed several programs focusing on storage capacity. The approach has been methodical. Working on previous studies (eg. CASTOR, GESTCO), GeoCapacity's multi-national approach, was essentially a collation of previous studies. GeoCapacity firstly analysed 23 European countries including most EU nations and surrounding nations such as Norway.

The assessment included the majority of onshore and offshore sedimentary basins, including emission sources-sink mapping. The assessment used various methodologies to calculate storage resource in each country. The resource calculation methods were all typically standard volumetric calculations with some efficiency factor to account for the fact that not all the pore space could be utilised.

This efficiency factor ranged from measured porosity values through to single percentage factor (eg. 1% of total pore space is accessible to CO2).

GeoCapacity was followed by the CO2StoP (CO2 Storage Potential in Europe Project) study which reviewed 27 EU nations. A single resource volumetric calculation using efficiency factors was used. Also a more detailed approach to storage characterisation identified over 400 storage formations, many with resource estimates. However, no cumulative figures were given due to a lack of uniform data in some of the nations.

In tandem with CO2StoP, and which can be viewed as the next logical step in site characterisation, a series of national studies in Norway and the UK have been completed, focusing on individual storage formations in their offshore basins. These detailed studies also take into account non-geological aspects of storage including economics, risk assessment, etc., which are factors as vital as the geology to enable a CCS project to proceed.

Europe has adopted a 'bottom-up' approach to site characterisation. Firstly completing studies at a multi-national level, collating existing knowledge that progresses to individual identification of storage formations using a single calculation method. This approach enables all countries covered in the assessment to identify all their storage basins, understand their total storage potential and then select the most prospective basins for further appraisal.

The North Sea is consistently identified as the most prospective area for storage. Unsurprisingly, the North Sea also hosts three commercial CCS projects in Sleipner, Snøhvit, and K12-B and is identified as the primary location for future CCS hub development. Using a single methodology to identify storage formations and their storage resources (eg. CO2StoP), provides consistency and enables comparison of potential sites for storage. Strategic, long-term national (and multi-national) CCS infrastructure planning is therefore possible through the 'bottom-up' approach. However, this approach can often be time consuming given the large datasets required and coordination of organisations.

Away from oil and gas fields, which often have extensive subsurface seismic and well data, knowledge of the subsurface can be sporadic, or completely absent. This results in either large assumptions of the resource or that basin/storage formation being omitted completely as it does not comply with data requirements. Hence, the level of detail in the bottom-up approach, where specific data for storage evaluation is obtained, becomes more important but even more time and cost intensive.

Southeast Asia

In contrast to Europe, the majority of countries in Southeast Asia (specifically Indonesia, Philippines, Malaysia, Thailand and Vietnam) have a 'top-down' approach, where the most prospective storage formation are being actively characterised first. The Asian Development Bank (ADB) funded a storage assessment study which undertook an assessment of the most prospective basins in several countries of Southeast Asia.

Although it was a multinational study, it focused on individual prospective areas including large (>10 million tonnes at injection rate of 100 tonnes per day per well) DGOF and/or areas with the best subsurface datasets. The latter could include DSF. By assessing these prospective storage formations only, the ADB study could use a single methodology (known as estimated ultimate recovery) that resulted in more restrained (but smaller overall) resource estimates.

The CCOP is expanding on previous assessments to include the majority of Southeast and East Asian nations including more basins whilst ensuring a single methodology for resource calculation. Prospective basins will also be identified and ranked to enable greater planning and development at the national and international level. The CCOP is therefore more akin to the CO2StoP European assessment.

The 'top-down' approach in Southeast Asia, of identifying the most suitable storage formations, is arguably a more efficient approach to storage development, focusing knowledge and funding resources on the regions with the highest potential. The top-down approach does not allow national planning for CCS infrastructure development when the total storage potential of the entire country is not known.

However, focusing on the most prospective basins, which typically host oil and gas fields, and will likely have higher density of subsurface data, and be well characterised and delivers more robust resource estimates.

Summary

This study collated and summarised the results from published regional assessments of nations globally. The analysis has found that:

• The published storage resources are vastly greater than those required for CCS to meet future emission reduction targets.

• Substantial storage resources are present in most of the high emitting nations of the world.

• Despite reliable methodologies to determine and classify regional storage resources being available and widely applied, there is no formally recognised international standard.

• The level of resource assessment undertaken and the availability of characterisation data varies greatly between regions.

• Regional resource assessments are not a substitute for the detailed site-scale appraisals of storage capacity required to support financial investment decisions for projects.

More information

The fully referenced paper can be downloaded from:

www.globalccsinstitute.com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