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Front cover: The 8th Dutch CCS Symposium in Rotterdam, organised by the Dutch National CCS research program CATO, was held onboard SS Rotterdam (Image ©Floris Scheplitz and CATO)

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Leaders - CCS in Asia

Projects and policy

Special report from the 8th Dutch CCS Symposium

Capture and utilisation

Transport and storage

China's low carbon policy objectives

With the global COP21 climate talks in Paris just around the corner, this Insight Briefing by BSR and The Climate Group provides an overview of China's climate policies, including its national emission reduction targets and emissions trading market, as well as the role of the country's sub-national governments and private sector in achieving a strong, low carbon economy.

By Xiaochen Zhang, Associate Director, Climate Change, BSR

Summary

In December world leaders will meet in Paris for a climate agreement that aims to drive a structural shift toward a low carbon global economy. Over the past 6 months, countries from around the world have submitted their intended plans for addressing climate change past 2020, called Intended Nationally Determined Contributions (INDCs). The INDCs provide an early indication of what a climate deal could look like at COP21. China's INDC, which was submitted in June, includes clear targets – and clear policy instruments on how to achieve them. Given the country's huge economic output, China will be vital to the success of an international climate agreement.

Based on an in-depth review of China's climate policy documents as well as insights from global experts, BSR and The Climate Group analyze China's climate actions so far, plans for COP21 and key challenges to success, in order to foster understanding and collaboration among key actors in the lead-up to COP21.

China's response to climate change

China has long understood that climate change is a potential constraint to prosperity and security. Over the past 20 years, climate change has moved from a sector issue to a top priority for the country's national strategy and a core component of the government's social and economic development initiatives, known as Five Year Plans. This attention to the issue has paid off. While China has maintained a growth rate of about 7% a year, by the end of 2014, its carbon emissions per unit of GDP had fallen by 33.8% compared to 2005 levels.

And in the past 12 months, China has dramatically scaled up its climate commitments through both bilateral and multilateral platforms. Not only do these developments signal the country's support for the international climate talks in Paris, but they are also creating new opportunities for the private sector over the long term.

China's national climate targets

For companies operating in any country, strong climate policy signals give emitters the confidence and incentives to incorporate relevant considerations into their long-term plans and daily activities. In this regard, China's INDC indicates to business that the country is taking climate change seriously. The country intends to:

• Peak carbon-dioxide emissions by 2030, or earlier if possible. According to an analysis of historical empirical data and submitted INDCs, developed countries, on average, peaked at between 10 and 22 tons of greenhouse gases (GHGs) per capita, when their GDP per capita was between US$20,000 and US$25,000 in 2010 dollars. China's goal is to peak emissions at 8 tons GHG per capita, and US$14,000 GDP per capita.

• Lower carbon-dioxide emissions per unit of GDP by 60-65% from 2005 levels. To achieve this by 2030, China must reduce its carbon intensity by about 3.6% to 4.1% every year. This goal is more ambitious than many developed countries.

• Increase the share of non-fossil fuels in primary energy consumption to around 20%, which includes a commitment to achieve 200 gigawatts (GW) of installed wind-power capacity and 100 GW of solar power by 2020. If China achieves this by 2030, it would be the equivalent of adding the entire US power grid, all in the form of non-fossil-fuel energy.

• Increase the forest stock volume by around 4.5 billion cubic meters above the 2005 level.

Emissions trading as a market instrument

While all of the above targets are critical, without a market price on carbon, the private sector won't have an effective tool to internalize emissions costs and invest in low carbon technologies. China has already explored the introduction of both an environmental tax and a carbon tax. In 2013 it introduced a pilot cap-and-trade program that covers seven major cities and provinces – and will be the world's second largest, after the European Union.

By the end of April this year, the total trading volume of China's pilot carbon market amounted to 22.9 million tons CO2 with turnover reaching more than RMB 784 million and an average price of RMB 34.3 per ton. Based on the initial results of these pilot programs, analysts believe the ideal price must be both ambitious enough to incentivize corporate action and affordable enough to accommodate the local economic situation.

In just five years, China's pilot carbon market program has become an important mechanism to drive financial innovation and cross-sector collaboration. The country now plans to launch a national emissions-trading system in 2017 to advance the deployment of clean technologies and raise revenue to invest in low carbon transformation at a national level.

Challenges and barriers to climate action

Until recently, China's climate efforts were driven by the country's somewhat disparate goals, including supporting energy security, reducing environmental degradation, restructuring the economy, building the country's international image, and securing a climate-resilient future. In the future, China may find it more difficult to balance the trade-offs between climate change and other economic goals when all the low cost and no-cost measures have been implemented.

To get round this, in 2012 the government proposed a blueprint, the "Ecological Civilization Construction," to better harmonize economic growth and nature. In the concept, binding emissions-reduction targets are used to encourage the structural change needed to sustain economic development while simultaneously improving environmental quality.

The challenge here is that China is still in the process of relatively rapid urbanization and industrialization, which means the economy cannot easily transition from its heavy reliance on fossil fuels for its primary energy consumption. Increasing the industrial sector's resource efficiency will increase costs for companies and households in the short term. So to encourage both industrial and consumer behavior change, China needs new market-based policy instruments. But in the absence of innovative policy instruments, basic market conditions and private-sector participation may pose challenges for China to reach its climate goals.

One example of this is China's power market, where the lack of competition has created barriers for renewable energy development. To address this, in March, China released an energy-reform plan to correct market distortions and improve market entry for private renewable-energy investors.

China has also developed regional pilot programs and laid out concrete rules to expand the amount of renewable-electricity sold to the national grids. However, a lack of coordination between renewable energy planning and overall electricity-development planning creates challenges when selling to the grid. This dramatically increases the risk around investing in renewables and is a major barrier to China scaling up renewable energy at an adequate speed to meet its INDC target.

For example in 2014-15, the annual wind-curtailment rate – the amount of wind-generated electricity that does not reach the grid because other energy sources are prioritized – rose by 6.8%, to 15.2%. The private sector will be unlikely to invest more in the renewable energy market if the curtailment of wind, solar and other renewable-energy sources is not effectively addressed. China must continue to accelerate its economic transition while creating market conditions to address these challenges.

Non-state actors bring climate solutions

Cities

Much of China's population lives in urban areas that are exposed to the risks of sea-level rise, storm surges, flooding and tropical cyclones. Losses from typhoons alone cost China RMB 8.4 billion (US$1.3 billion) each year between 1994 and 2005. This has put Chinese cities at the center of the country's climate discussions, and many city governments have introduced forward-looking initiatives to address climate change by "greening" traditional sectors, expanding emerging low carbon industries and growing the related service sectors.

On September 16, on the heels of China's INDC announcement in June, state, provincial, city and county leaders signed a "U.S.-China Climate Leaders' Declaration," through which 11 Chinese provinces and cities pledged to peak their carbon emissions far earlier than the Chinese national target of around 2030. Beijing, Guangzhou and Zhejiang pledged to peak their emissions 10 years earlier, by 2020, and Shenzhen and Shanghai pledge to peak emissions by 2022. Many of these provinces and cities will also develop regional and local low carbon development action plans, which will accelerate economic structural change and create market opportunities to scale up clean technologies.

Businesses

The Chinese government is increasingly looking to the private sector to help meet the country's climate change goals. According to UNEP, China requires RMB 2 trillion in investment every year between now and 2020 to grow its key green sectors. To achieve this, two thirds of the investment must come from domestic and international financial and capital markets.

Based on what has happened elsewhere around the world, it's clear that the private sector will not invest the amount needed unless enabling public policies and incentives are in place. Fortunately, China's newly released climate plan gives companies operating in China – including companies that are domestically owned, state owned, or multinational with supply chains in the country – clear policy signals. The more stringent policy environment will encourage firms to incorporate environmental costs into their commercial calculations, and these policies will also create huge market opportunities for business.

And already, both Chinese investors and business are taking action. Major multinationals with suppliers in China are joining collaborative platforms designed to increase renewable energy and reduce carbon intensity. The We Mean Business coalition contains platforms for businesses to address issues including short lived climate pollutants, deforestation, energy efficiency and carbon capture and storage. These platforms are ready to welcome increased participation from Chinese companies.

Conclusion

Between 2005 and 2014, China achieved a 3% annual reduction of its carbon intensity, which is a greater rate than most other countries have ever been able to achieve. With China's strong – and growing – investment in renewables, nuclear and energy-efficiency, as well as the country's efforts to lower its coal consumption, in 2014 global emissions held steady for the first time without an economic downturn.

Given China's recent active participation in the global climate talks process and its ambitious targets outlined in its INDC, it is clear that China is working hard to build a low carbon future. With the new momentum created by the 2014 US-China Joint Announcement on Climate Change which was bolstered further in September, the deep decarbonization call from the G7 in June, and the increasing global consensus for a successful global climate agreement in Paris that was reinforced by major businesses, sub-national governments and civil society leaders at Climate Week NYC in September, we believe China will continue to contribute to the global efforts in limiting the global temperature rise to 2°C in the future.

More information

To download the full report with references visit:

www.theclimategroup.org

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Carbon Capture & Storage in Taiwan

Taiwan has established a national energy program for clean coal and carbon reduction to promote research and development, and is operating several CO2 capture pilot plants.

By David Shan Hill Wong, Professor, National Tsing Hua University, Taiwan

According to its Bureau of Energy, Taiwan emitted about 250 Mteq of carbon dioxide (CO2) by fuel combustion in 2013. The industrial sector was the largest producer, accounting for about 49% of the emission. However, emission has leveled off since 2007, and carbon intensity has actually decreased from a peak value of 0.0215 kg/US$ in 2001 to 0.0163 in 2013.

The government has introduced the first draft of the greenhouse gas (GHG) reduction bill in 2007, and the final version was passed in May 2015. The long term goal is to achieve 50% reduction in CO2 emission to less than 125 Mteq by 2050. This will be implemented through a series of steps including mandatory reporting, voluntary reduction, introduction of performance awards and establishment of cap and trade.

Coal accounts for about 30% of energy supply of Taiwan. About 70% of the coal is used for power generation and the rest is used for iron and steel, cement, and other energy intensive industries. Due to its stable supply and inexpensive, it is desirable that coal can continue to be an important element of Taiwan's energy supply portfolio. However, such an expectation can only be fulfilled if the CO2 emission from coal can be mitigated. Hence the ministry of science and technology (MOST) had established a national energy program for clean coal and carbon reduction to promote research and development in the following four areas:

1. Advanced Power Generation Technology – such as ultra-supercritical combustion (USC), advanced USC, integrated gasification combined cycle (IGCC), integrated gasification fuel cell (IGFC), super-efficient engine and steam turbine generator.

2. Clean Process of Coal Combustion - gasification, fluidized bed, production of hydrogen, methanol, and chemical goods, coal 1iquefaction for transportation fuels etc,

3. Environmental Control and Mitigation – focused on CO2 capture, storage and utilization (CCSU).

The Hoping Cement plant in Hua Lien, Taiwan

4. Industrial Reduction of CO2 Emissions – such as CO2 emission reduction in petrochemical, iron and steel, cement, pulp and paper industries.

These programs emphasized on the mobilization of the academia to work with industry so that relevant process technologies can be developed and deployed. We are have now completed a 3-year first phase program and is now executing a second phase 3-year program.

CO2 Capture pilots

In the area of carbon capture technology, we have focused on chemical absorption, carbonation and chemical looping. Chemical absorption is emerging to be the current technology that is being demonstrated to be commercially viable. Its main advantage is its applicability to existing power plant as a simple add-on unit.

The main challenges of this process are the substantial energy penalty and large equipment size that is required. Therefore, one of the goals is to prepare the engineers of our industry for the design, construction and operation of such processes. Comprehensive research and development on various aspects of chemical absorbent such as solvent developments, heat integration, control, degradation prevention etc. were carried out. Moreover, due to the limited land available for exisiting power plants in Taiwan, the focus on the use of rotating packed bed to reduce the size of the absorber.

A small scale pilot plant was constructed in the Kaohsiung plant of the China Steel Corporation, Taiwan. The design capacity is 100 kg CO2 captured per day. The plant is equipped with a rotating packed bed absorber, a packed bed absorber and a packed bed stripper. A combustion product of a blast furnace gas was used as the inlet flue gas stream. It was found that the rotating backed bed can achieve the same degree of carbon dioxide capture using the same energy expenditure with volume about 1/3 of the packed bed absorber. This size reduction without additional energy penalty can be achieved with 30wt% MEA solution, other advanced amines as well as dilute aqueous ammonia solutions.

Using the experience learned from this small scale pilot, a 1 Ton CO2 captured per day was designed and is now being constructed in the Formosa Plastic Petrochemical Complex in Mai Liao, Taiwan and is expected to be commissioned by the end of the year.

Carbonation of alkali waste is a capture and utilization technology that is especially suited for energy intensive industries such as steel, cement industries that produces wastes such as slag, ash etc. The challenge is to overcome gas-liquid-solid mass transfer limitation so that the carbonation rate is sufficiently fast. Again rotation packed bed technology was used.

In the Kaohsiung plant of the China Steel Corporation, Taiwan, we have field tested the technology using a small pilot apparatus capable of capturing 200 kg per day of CO2 using the same gas source as in the chemical absorption. We found that 90% removal can be achieved and for 1 ton of blast furnace slag, 0.2 to 0.3 ton of CO2 can be captured. Moreover, the carbonation process not only stabilized the waste so that they can serve as construction materials with properties comparable or better than Portland cement, and the process also works better when waste water of the steel plant was used.

Hence the carbon dioxide capture and utilization process also serves as an integrated waste treatment process. Another field test was carried in Tung Ho Steel using electrical furnace slag. Similar favorable results were obtained. A second generation 7-ton per day facility is now being constructed with field test plans in other steel companies as well as in a petroleum refinery in Mai Liao.

Chemical looping combustion (CLC) is one of the possible next generation combustion technology. The idea is to use metal oxide as oxygen carrier in the oxidizer, thus producing a flue gas stream from which CO2 can be easily captured. While chemical looping can also serve as a carbon capture technology in calcium looping in which CaO is used in a carbonation chamber to produce calcium carbonate and the calcium carbonate is reduced back to CaO in a calcination chamber to produce CO2 ready for sequestration. Fresh calcium carbonate (limestone) is fed to the calcination chamber and part of CaO is removed and recycled as material in cement product.

This particular process is fitted for the cement industry. The Industrial Technology Research Institute (ITRI) established the world's largest pilot plant (High Efficiency Calcium Looping Technology, HECLOT) for carbon dioxide capture using calcium looping in 2013 in collaboration with the Taiwan cement company. The facility is located in the Hoping cement plant in Hua Lien on the east coast of Taiwan. It is capable of capturing 1 ton-CO2/hr using a fluidized bed carbonator and a rotary kiln calciner, achieving capture and calcination efficiency of over 90%. HECLOT is able to achieve an initial capture cost lower than $30 per tonne of CO2, and is expected to be further reduced with economy of size and accumulation of know-how. HECLOT won the 2014 R&D 100 Awards in the "Environmental Technologies" category.

The HECLOT (High Efficiency Calcium Looping Technology) facility in the Hoping cement plant

CO2 storage

While research and development capture technology is moving along as scheduled, there is much controversy in sequestration. Many onshore oil and gas structures, deep salines aquifers have been identified, many on the western side of the island. Extensive geophysical and sesmic studies of the geological characteristics, development of monitoring of soil, underground water, fault activities and injection simulation have been carried out for Yong-Ho-Shan deleted gas structure in Miao Li, Taiwan and offshore structures in Taixi basin off the Chang Bing industrial park.

A pilot injection project was planned at the Yong-Ho-Shan site. Taiwan is situated on the collision zone of the Philippines sea plate and Eurasian continental plate. Earthquakes are part of our daily life. the fear of a major quake is deeply ingrained in the general public. Though the chance of initiating a quake by the start of a pilot project is minimal, it cannot be absolutely eliminated scientifically. Much more outreach and communication efforts have to be made to secure acceptance of the general public and local citizens.

Conclusion

In summary, Taiwan has moved along in the development of capture and sequestration focusing on being ready technically for state-of-the-art technology and development of our own niche. The need for CO2 management has also initiated collaborations between the government, industry and academia that have been practiced across the world: with government leading the way in terms of policy, academia providing their expertise and industry providing a substantial part of funding, land and manpower to support pilot and demonstration projects.

More information

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Korea Global CCS Symposium 2015: redefining deployment priorities and developing collaborative partnerships

In October 2015 the Global CCS Institute sponsored a global carbon capture and storage symposium in Gwang-gu, South Korea, including an Institute Member's Meeting. In an 'Insight' on the Institute's website, Jessica Morton, Public Engagement Adviser and South Korea Country Manager, reported on developments from the meeting and the status of this vital low-carbon technology in South Korea.

South Korea continues to support the deployment of CCS and in recent years the country has made significant investments into the research and development of a variety of CO2 capture technologies, applications and industries. As a result of this investment South Korea now has two large-scale CCS projects in the pipeline. In order for these two large-scale projects to move forward it is important that efforts continue to be made to deepen the understanding of South Korea's onshore and offshore CO2 storage potential, and to ensure appropriate legal and regulatory frameworks are in place.

Shifting the emphasis from research and development towards addressing these challenges was the focus of the Korea CCS Association's (KCCSA) 2015 Global CCS Symposium in Gwang-gu, South Korea 13 – 14 October 2015. The event was sponsored by the Global CCS Institute and incorporated an Institute Members' Meeting in the agenda.

South Korea ready to focus on deployment

In his opening remarks for the Symposium, Park Sung Chul, Chairman of the KCCSA, set the tone of the event, noting it was "..time for Korea to move onto the next stage, from research to dissemination." He further observed that South Korea was at a turning point where the significant gains made in CO2 capture technologies needed to be applied to large-scale demonstration project deployment.

Emerging over the course of the Symposium was the consensus that progress must be made in identifying appropriate CO2 storage sites, educating the public about climate change and energy as well as developing relevant policy, laws and regulations to facilitate project development. Collaboration and discussion between Korean organisations was also highlighted as a milestone achievement crucial for moving forward.

Through the Korean CCS Master Action Plan the Government has confirmed its commitment to CCS by allocating substantial resources (over US $430 million) towards advancing the deployment of CCS projects in South Korea. To date the majority of funding has been put toward research into CO2 capture technologies, however investments are beginning to be made in developing CO2 monitoring and measurement expertise.

The Korea CO2 Storage Environmental Management Research Centre (K-COSEM) will shortly commence a pilot scale CO2 shallow injection project examining the impacts of CO2 on groundwater and soil with the aim of building skills and developing appropriate monitoring tools. The findings of this activity will help inform some of the other responsibilities K-COSEM have been tasked with, including developing public engagement materials and contributing to the development of a legal and regulatory framework. This is a positive step forward for CCS development in South Korea.

International experience

Throughout the Symposium a number of short and medium term goals for CCS in Korea were identified and this provided a useful platform for progress. It was emphasised that the Korean context for CCS is not dissimilar to a number of other countries that have CCS projects in the pipeline and therefore, South Korea is in a strong position to draw on these experiences and apply them appropriately.

For example, it is unlikely that there are sufficient Enhanced Oil Recovery opportunities in Korea to drive CCS project development. Therefore policy makers are looking to applicable examples from other jurisdictions to support deployment. The United Kingdom's recent policy advancements have facilitated the progress of a number of CCS projects. The knowledge and lessons that have emerged from this experience will likely prove useful within Korea.

There are also opportunities for international collaborations in the field of CO2 storage. At this point in time, the Ulleung Basin, which contains deep saline formations and is located off the South East coast of Korea is being studied as a potential site for CO2 storage. There is a wealth of international CCS project expertise that could be drawn upon to inform further site characterisation as well as potential injection and monitoring activities.

All of these examples are clear opportunities for collaboration between South Korea and international CCS stakeholders. The symposium agenda was targeted in identifying the current barriers that are affecting CCS deployment in South Korea. What remains to be seen is how the Korean CCS community will utilise its internal expertise, the experience of the international community and the significant resources that are available to move further toward the operation of a large-scale CCS project in Korea.

More information

www.globalccsinstitute.com/insights

China-Australia Geological Storage of CO2 Project Phase Two

Phase two of the China Australia Geological Storage of CO2 (CAGS2) project aimed to build on the success of the previous CAGS project and promote capacity building, training opportunities and share expertise on the geological storage of CO2. The project was led by Geoscience Australia (GA) and China's Ministry of Science and Technology (MOST) through the Administrative Centre for China's Agenda 21 (ACCA21).

CAGS2 has successfully completed all planned activities including three workshops, two carbon capture and storage (CCS) training schools, five research projects focusing on different aspects of the geological storage of CO2, and ten researcher exchanges to China and Australia. The project received favourable feedback from project partners and participants in CAGS activities and there is a strong desire from the Chinese government and Chinese researchers to continue the collaboration. The project can be considered a highly successful demonstration of bi-lateral cooperation between the Australian and Chinese governments.

Through the technical workshops, training schools, exchange programs, and research projects, CAGS2 has facilitated and supported on-going collaboration between many research institutions and industry in Australia and China. More than 150 experts, young researchers and college students, from over 30 organisations, participated in CAGS2. The opportunity to interact with Australian and international experts at CAGS hosted workshops and schools was appreciated by the participants, many of whom do not get the opportunity to attend international conferences. Feedback from a CAGS impact survey found that the workshops and schools inspired many researchers and students to pursue geological storage research.

The scientific exchanges proved effective and often fostered further engagement between Chinese and Australian researchers and their host organisations. The research projects often acted as a catalyst for attracting additional CCS funding (at least A$700,000), including two projects funded under the China Clean Development Mechanism Fund. CAGS sponsored research led to reports, international conference presentations, and Chinese and international journal papers.

Recommendations

• There is an increasing willingness from China to provide co-funding towards a future CAGS program. There are a number of Chinese demonstration projects that could contribute significant in-kind and domestic cash funding. This provides an opportunity to leverage funding and expertise to further enhance Australian-Chinese cooperation on geological storage of CO2.

• The application of geological storage of CO2 in China will be mostly associated with enhanced oil recovery (EOR) and enhanced shale gas recovery (ESGR). While CCUS-EOR is not practical for Australia due to the type of oils and geological formations found in Australia, it is recommended to maintain cooperation with China in the research areas of CO2-ESGR and enhanced water recovery. This could potentially benefit Australia's nascent shale gas industry. China has successfully started production of shale gas using ESGR in the Ordos Basin and there are opportunities for cooperation, especially in terms of monitoring technologies and geological modelling and assessment.

• Most of the research under CAGS has been conducted at a national, regional and provincial level but future work should focus on where concrete activities and projects are likely to happen. A key target area is the Xinjiang province and the planned CCUS demonstration project at the Zhundong oilfield in the Junggar Basin, but it is also recommended to link in with other active geological storage demonstration projects in China such as the Shenhua Ordos or Jilin oilfield projects.

• Focus on challenges facing both Australia and China, e.g. storage in arid environments, baseline mapping of groundwater resources, application of geological storage assessment workflows, development of shale gas resources, and tackling the challenge of developing cost-effective, near-surface, monitoring technologies that can monitor over large areas.

• The network established by CAGS is an invaluable asset, e.g. young researchers, experienced researchers, company representatives, and government officials. Further efforts should go into maintaining and strengthening the network, including the international partners. This could be achieved by combining capacity building with targeted research, which is often overlooked in the bilateral cooperation space. It is also recommended to expand the capacity building program to include key provincial government representatives.

• It is recommended to continue to engage in capacity building through workshops and schools. This was a very effective model and should be included in any future cooperative program. The workshops and schools had a number of important benefits beyond direct knowledge transfer including: increasing cooperation amongst Chinese institutions; inspiring students and researchers to pursue geological storage research; facilitating increased collaboration between international experts and Chinese participants; and increasing resource allocation and funding to CCS research within the participants' institutions.

CAGS has established a network of key CCS/CCUS (carbon capture, utilisation and storage) researchers in China and Australia. This is exemplified by the fact that 4 of the 6 experts that provided input on the "storage section" of the 12th Five-Year plan for Scientific and Technological Development of Carbon Capture, Utilization and Storage, which laid out the technical policy priorities for R&D and demonstration of CCUS technology in China, were CAGS affiliated researchers.

The substantial contribution of CAGS to China's capacity building and policy on CCUS has been gratefully acknowledged by the Chinese Government.

Aim and objectives

CAGS2 was designed to build upon the cooperation established between Australia and China during the first phase of CAGS. The project aimed to further develop China and Australia's technical skills in the area of geological storage of carbon dioxide (CO2) through a number of capacity building activities; training opportunities; sharing of expertise through scientific exchanges; and advancing geological storage science through sponsored research projects in China. The planned outcomes of the project were as follows:

• Enhance Australia's bilateral relationship with China through the successful implementation of project activities;

• Develop and expand ties of cooperation between Australia and China in the geological storage of CO2;

• Identify areas where cooperation on the development and demonstration of the geological storage of CO2 can be enhanced for mutual benefit; and

• Identify opportunities for new joint projects in the geological storage of CO2.

Lessons Learned

Throughout the project implementation, observations have been made on what worked well and what could be improved. The CAGS impact survey provided additional insights from the participants. Some of the key lessons learned are:

• Establishing a collaborative working relationship with the project partner is the key to success. Over the past five years, GA and ACCA21 have worked as a team and built a strong cooperative relationship. This relationship has provided a solid foundation for the project implementation. The trust and good will from both sides enabled Australian and Chinese project teams to work together through issues and reach agreements.

• There was a deliberate effort in CAGS2 to be more "hands off" with the research projects and exchanges, compared to CAGS1. We received comments that some of the research projects or exchanges were not well organised by the host. It is recommended that future exchanges or projects maintain a strong central coordination team to ensure projects run smoothly.

• The workshops and schools continue to be an effective mechanism for knowledge exchange and networking. In feedback compiled through the CAGS impact survey, Chinese researchers commented that they are able to deepen their understanding in the latest research and developments in China and overseas and expand their professional networks. The opportunity to interact with Australia and international experts at the CAGS hosted workshops and schools was appreciated by the participants, many of whom do not get the opportunity to attend international conferences and therefore are not exposed to the latest international research developments. The international experts in turn found the workshops and schools valuable because it enabled them to expand their network in China and form new research collaborations. This is an excellent model and should form the basis of any future cooperative program.

• Simultaneous translation services during the workshops were greatly appreciated by the participants and fostered a more collaborative environment and open discussion.

• All surveyed Chinese workshop participants considered that their involvement led to an increased awareness and priority placed on CCS within their organisations, which in some organisations, led to increased funding and resources allocated to CCS research. For Australian and international participants, the capacity building events provided a great opportunity to learn more about Chinese CCS research, often not presented at international conferences, and provided an opportunity to engage with a greater number of Chinese institutions.

• We received feedback that the level of research funding for the projects was fairly modest and could only support non-core activities. There could be greater impact if larger research projects were co-funded that supported active demonstration projects. Nevertheless, the research projects often acted as a catalyst for attracting additional CCS funding.

• The exchanges were generally very successful and led to lectures, publications and sometimes significant new Chinese funding for ongoing collaborative research. Most participants have continued collaboration with their hosts after their exchange.

Conclusions

• CAGS has been a very successful program and there is a strong desire from China to continue the collaboration. There is also a strong desire from Australian researchers to continue the engagement, with a greater willingness to undertake research activities based in China.

• During the course of CAGS1 and CAGS2, China has changed from being a minor player in CCS research to becoming a leader. CAGS can take some credit for this change by facilitating the communication and cooperation between Chinese researchers and government departments. We are starting to see Chinese CCS/CCUS policy undergo similar transformations.

• CAGS has provided Chinese scientists with largely unfettered access to current Australian (and international) CCS research and policy, with opportunities to take home to China learnings and insights for immediate application.

• CAGS has increased the impact and influence of Australian CCS research by influencing the course of China's CCS research and policy. The future actions of China (being a much larger economy than Australia), should, in turn, influence the progress of CCS in other countries.

More information

The full Summary Report can be obtained from Geoscience Australia:

www.ga.gov.au

Feitz, A., Gurney, J., Huang, L., Zhang, J. and Jia, L. 2015. China Australia Geological Storage of CO2 Project Phase Two (CAGS2): Summary report. Record 2015/06. Geoscience Australia, Canberra. **dx.doi.org/10.11636/Record.2015.006**

Global Status of CCS: 2015

Now in its sixth year, the Global Status of CCS 2015 profiles two large-scale CCS projects that became operational in 2015 – the Canadian Quest project and the Uthmaniyah CO2-EOR Demonstration Project in the Kingdom of Saudi Arabia. www.globalccsinstitute.com

At the launch of this year's report, the number of operational projects stands at 15, with another seven projects in various stages of construction and due to come online in the next 18 months. Up to 28 million tonnes of carbon dioxide emissions will be captured by existing operational carbon capture and storage projects this year.

These 22 projects hold the key to closing the gap between current international climate commitments, and what scientists say is needed in order to meet a global warming target of 2° Celsius.

Speaking from the launch of Shell's landmark Quest project in Alberta, Canada, the CEO of the Global CCS Institute, Brad Page, said the substantial gap between international climate commitments and what scientists say is needed means all available technologies must be used.

"If the world is serious about tackling the reality of climate change, we have to make full use of all available technology options – and especially CCS," said Mr Page.

"It is vital that we share the knowledge and learnings highlighted by these trailblazing CCS projects and apply them to projects in operation, projects currently being built, and projects at the earliest stages of assessment.

"These major projects show CCS is a proven technology that is reducing CO2 emissions by millions of tonnes in different countries around the world.

"CCS has a vital role to play as part of the overall technology mix required to meet the internationally agreed goal of limiting the impact of global warming to two degrees. Now is the time for decision makers to make a renewed commitment to this vital low-carbon technology."

By 2017 these 22 CCS projects will be able to capture and store 40 million tonnes of CO2 emissions per year. This is equivalent to taking 8 million cars off the road.

The Intergovernmental Panel on Climate Change's Fifth Assessment Synthesis Report, released in November 2014, highlights the importance of CCS as a vital climate mitigation technology. Without CCS, the cost to avoid a global warming of more than 2°C would likely increase by 138 per cent – more than double.

"It's important to realise that CCS is not just about power generation emissions," said Mr Page.

"CCS is the only technology that can achieve large reductions in emissions from industrial processes such as manufacturing iron and steel, chemicals and cement. The industrial sector as a whole accounts for around 25 per cent of the world's CO2 emissions"

In addition to highlighting the combined capture potential of current and pending CCS projects, the Global Status of CCS 2015 also highlights the global disparity between CCS and other low-carbon technologies from a policy and regulatory perspective.

"Policy and regulatory support are the key to stimulating investment in CCS, and it's important to recognise that since 2007, total global CCS investment has been less than US$20 billion," said Mr Page.

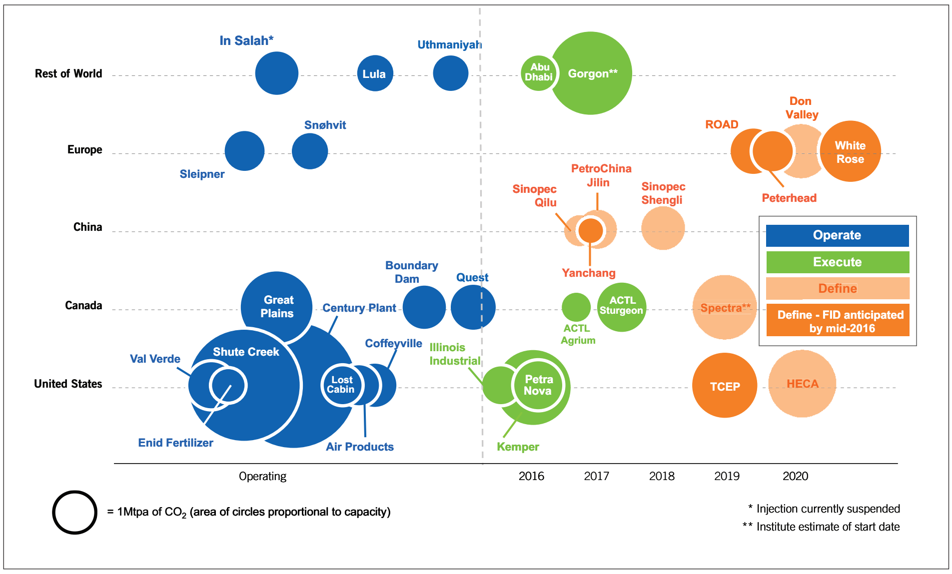
"Compare that to investment of around 100 times that amount for renewable power generation technologies over the same timeframe. A disparity in policy support is the main reason for this.

"Ahead of the COP21 meeting in Paris, there remains a substantial gap between total country commitments to CO2 emission reductions, and what science tells us we need to do.

The Global Status of CCS 2015 also identified that tens of millions of tonnes of CO2 have been successfully injected and stored since the early 1970s, in a variety of storage pilot projects, large-scale projects involving geological storage, or in enhanced oil recovery projects.

"When it comes to understanding CO2 storage, it's important to recognise that the technology is well proven and is not a barrier preventing the implementation of commercialised CO2 storage as part of the global deployment of CCS," said Mr Page.

"Secure geological storage sites can be selected, characterised and operated based on well-established risk management principles gained from decades of industry experience."



Actual and expected operation dates for large-scale CCS projects in the Operate, Execute and Define stages by region and project lifecycle stage (Source: ©Global CCS Institute)

Strengthening the foundations for accelerating CCS deployment

With a further 12 projects in the early stages of planning, the total number of large-scale CCS projects currently sits at 45, with a total CO_2 capture capacity of 80 Mtpa. This level of capture capacity is dwarfed by the amount of CCS deployment required in the next 20-30 years to meet climate targets, says the report, estimated at approximately 4,000 million tonnes of CO_2 captured and stored per annum by 2040.

The lead times to translate lessons from operational projects and research and development (R&D) into a next generation plant can take years. It can also take a number of years to properly characterise a storage site to support a final investment decision. The same applies to policy and legal and regulatory improvement timelines.

Strong policy is vital to the challenge of accelerating deployment of CCS to the levels required to meet international climate target, says the report, and urgent action is required this decade to implement the incentive frameworks that can help drive cost-effective CCS deployment in the 2020s and beyond.

In order to facilitate the development of the next generation of CCS projects, the report reccommends several policy objectives.

1. Predictable policies for investors that do not disadvantage CCS

The Institute published an update of its CCS Policy Indicator in August 2015. In it, countries are ranked into four quadrants depending on their policy support for CCS, relative to the level of interest they should have in the technology (see Figure). The United Kingdom (UK), the US and Canada are in the 'upper tier'.

These countries have together implemented a combination of:

• Direct regulation to require power generators to reduce emissions intensity

• Government funding of large-scale CCS projects and R&D

• Fiscal and market-based incentives, including carbon pricing and tax credits

• Supportive legal and regulatory frameworks governing CO_2 storage.

2. Further deployment of CCS-specific law and regulation across the globe

The development of CCS-specific law and regulation remains a critical issue globally, for both governments and project proponents alike.

The Institute's recently released CCS Legal and Regulatory Indicator10 reveals that only a small number of countries to date have developed comprehensive frameworks capable of addressing the many issues associated with project deployment. Australia, Canada, Denmark, the US and the UK, all possess CCS-specific laws or existing laws that support most parts of the CCS project lifecycle.

The large majority of jurisdictions, however, have yet to develop comprehensive frameworks and have limited legislation capable of regulating CCS projects. As such, it will be increasingly important for countries in this group that have strong policy commitments to the technology, and projects in the development pipeline, to progress their domestic legal and regulatory regimes.

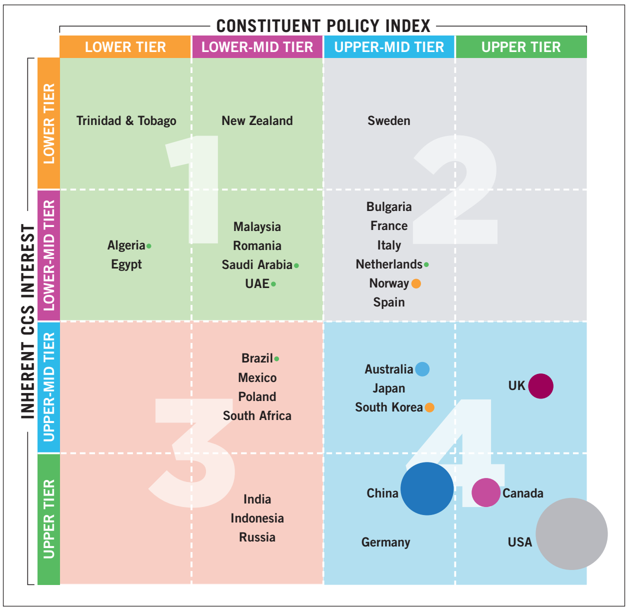
3. Incentivise selection and characterisation of storage sites to support final investment decisions by projects

Secure CO_2 geological storage at large-scale has already been demonstrated at a number of successful projects around the world. The technology is already available to select, characterise, safely operate, complete and close storage projects.

To support the acceleration of CCS deployment required by emissions reduction targets, storage needs to be achieved on a much larger scale than at present.

4. Research and development efforts to advance more cost-effective capture technologies

As we look to the future of carbon capture technology, it is clear that the integration of two key focus areas will drive down capital and



CCS Policy Indicator 2015 results. Size of bubbles denotes number of projects as of October 2015 (Source: ©Global CCS Institute)

operating costs. First, the lessons learned from the portfolio of projects described earlier will provide valuable information for decreasing the cost of design, construction and operation of future carbon capture facilities. Second, there must be a continuing focus on R&D efforts to further reduce costs beyond those that emerge from the learnings of operational projects.

5. Progress must be accelerated in developing countries

The majority of the world's CO_2 emission reductions under a 2°C scenario must be realised in developing (non-OECD) countries, primarily in Asia.

A particular challenge for developing countries is the 'energy trilemma' – balancing the goals of energy access, energy security and environmental sustainability. CCS can help developing countries achieve these goals by enabling them to continue to utilise their indigenous fossil fuel reserves.

Reducing the costs of CCS deployment and access to international funds are critical to support its widespread use in developing countries through 2030 and beyond.

More information

The complete summary report and key findings can be downloaded here:
www.globalccsinstitute.com

World Energy Outlook 2015 - energy transition underway

The latest World Energy Outlook sees clear signs that the energy transition is underway, but warns strong direction is needed from Paris climate summit.

The report underlines that the single largest energy demand growth story of recent decades is near its end: China's coal use reaches a plateau at close to today's levels, as its economy rebalances and overall energy demand growth slows, before declining.

India moves to centre stage in global energy, with high levels of economic growth, a large (and growing) population and low (but increasing) levels of energy use per capita all pushing energy demand to two-and-a-half-times current levels.

Overall, world energy demand will grow by nearly one-third between 2013 and 2040 in the central scenario of WEO-2015, with the net growth driven entirely by developing countries. The links between global economic growth, energy demand and energy-related emissions weaken: some markets (such as China) undergo structural change in their economies and others reach a saturation point in demand for energy services.

All adopt more energy efficient technologies, although a prolonged period of lower oil prices could undercut this crucial pillar of the energy transition; diminished incentives and longer payback periods mean that 15% of the energy savings are lost in a low oil price scenario. Lower prices alone would not have a large impact on the deployment of renewables, but only if policymakers remain steadfast in providing the necessary market rules, policies and subsidies.

In advance of the critical COP21 climate summit in Paris, there are clear signs that an energy transition is underway: renewables contributed almost half of the world's new power generation capacity in 2014 and have already become the second-largest source of electricity (after coal). The coverage of mandatory energy efficiency regulation has expanded to more than one-quarter of global energy consumption.

The climate pledges submitted in advance of COP21 are rich in commitments on renewables and energy efficiency, and this is reflected in the WEO-2015 finding that renewables are set to become the leading source of new energy supply from now to 2040. Their deployment grows worldwide, with a strong concentration in the power sector where renewables overtake coal as the largest source of electricity generation by the early-2030s. Renewables-based generation reaches 50% in the EU by 2040, around 30% in China and Japan, and above 25% in the United States and India.

The net result of the changes seen in the WEO-2015 central scenario is that the growth in energy-related emissions slows dramatically, but the emissions trajectory implies a long-term temperature increase of 2.7° C by 2100. A major course correction is still required to achieve the world's agreed climate goal.

"As the largest source of global greenhouse-gas emissions, the energy sector must be at the heart of global action to tackle climate change," said Dr. Birol. "World leaders meeting in Paris must set a clear direction for the accelerated transformation of the global energy sector."

"The IEA stands ready to support the implementation of an agreement reached in Paris with all of the instruments at our disposal, to track progress, promote better policies and support the technology innovation that can fulfil the world's hopes for a safe and sustainable energy future."

Key findings for CCS

• An energy sector transition is underway in many parts of the world. Policies to support the transition are increasingly being adopted, the US Clean Power Plan and China's newly announced carbon trading scheme to take effect in 2017 being among the most recent.

• In the New Policies Scenario (the central scenario of WEO-2015), the cautious implementation of new and announced policies, including the energy sector components of the climate pledges, supports the greater adoption of low-carbon technologies and improved energy efficiency. Energy demand grows at 1.0% per year to 2040, about half the average annual rate since 1990, thanks to increased energy efficiency in enduses and structural changes to the economy. The power sector decarbonises more quickly than ever before: CO2 emissions from power generation grow at only one-fifth the rate at which power output rises to 2040, breaking a longstanding one-for-one relationship.

• Despite positive progress, efforts are not yet enough to move the world onto a pathway consistent with the 2 °C climate goal. In the New Policies Scenario, energy-related CO2 emissions increase to 36.7 Gt in 2040, 16% higher than in 2013. Full implementation of the unconditional pledges made for COP21 by more than 150 countries by mid-October 2015 would require cumulative investment of $13.5 trillion in lowcarbon technologies and energy efficiency until 2030.

More information

The executive summary and factsheets can be downloaded here:

www.iea.org

Shell launches Quest carbon capture and storage project

Shell has officially opened the Quest carbon capture and storage (CCS) project in Alberta, Canada, and begun commercial operations there.
www.shell.ca

Quest is designed to capture and safely store more than one million tonnes of carbon dioxide (CO_2) each year – equal to the emissions from about 250,000 cars. Quest was made possible through strong collaboration between the public and private sectors aimed at advancing CCS globally.

As part of its funding arrangements, Shell is publically sharing information on Quest's design and processes to further global adoption of CCS. Quest draws on techniques used by the energy industry for decades and integrates the components of CCS for the large-scale capture, transport and storage of CO_2. CCS is one of the only technologies that can significantly reduce carbon emissions from industrial sectors of the economy.

Speaking at the official opening, Shell's Chief Executive Officer Ben van Beurden said: "Quest represents a significant milestone in the successful design, construction and use of carbon capture and storage (CCS) technology on a commercial scale. Quest is a blueprint for future CCS projects globally. Together with government and joint-venture partners, we are sharing the know-how to help make CCS technologies more accessible and cost-effective for the energy industry and other key industrial sectors of the economy."

Quest will capture one-third of the emissions from Shell's Scotford Upgrader, which turns oil sands bitumen into synthetic crude that can be refined into fuel and other products. The CO_2 is then transported through a 65-kilometre pipeline and injected more than two kms underground below multiple layers of impermeable rock formations. Quest is now operating at commercial scale after successful testing earlier this year, during which it captured and stored more than 200,000 tonnes of CO_2.

Quest was built on behalf of the Athabasca Oil Sands Project joint-venture owners Shell Canada Energy (60 per cent), Chevron Canada Limited (20 per cent) and Marathon Oil Canada Corporation (20 per cent), and was made possible through strong support from the governments of Alberta and Canada who provided C$865 million in funding.

A CO_2 injection well at Shell's Quest carbon capture and storage project in Canada (Image ©Shell)

"Quest is a blueprint for future CCS projects globally" - Ben van Beurden (Image ©Shell)

Collaboration is continuing through Quest between Shell and various parties in an effort to bring down costs of future CCS projects globally.
This includes cooperation with the United States Department of Energy and the British government on research.

"The secondment from the UK's Energy Technologies Institute (ETI) to the Quest CCS project is an example of British and Canadian cooperation in cutting-edge low-carbon technologies," said Howard Drake, British High Commissioner to Canada. "This research-focused partnership will help to develop CCS expertise on both sides of the Atlantic in an effort to advance the innovative solutions demonstrated at Quest."

The ETI, the University of Birmingham, the British government and Shell will support an eight-month secondment of a doctoral student at Quest, to deliver on the UK Canada Joint Statement on CCS issued in 2014.

Support from the local community was essential to building Quest. Shell initiated public consultation in 2008, two years before submitting a regulatory application. Public consultation was developed in collaboration with the Pembina Institute, a Canadian think tank focused on energy issues. A community advisory panel of local leaders and residents will regularly review results from Quest's monitoring program.

Can coal power plants meet CO2 emissions standards without CCS?

A white paper from the Electric Power Research Institute (EPRI) looks at the potential for coal power plants to meet new CO2 emission performance standards without partial CCS.

The U.S. Environmental Protection Agency (EPA) released its "new source performance standard" (NSPS) on August 3, 2015, requiring new coal power plants in the United States to emit no more than 636 kg (1400 lb) of carbon dioxide (CO2) per megawatt-hour (MWh) of gross power produced.

Summary

Current carbon capture and storage (CCS) technologies and anticipated near-term commercial offerings for systems to reduce carbon dioxide (CO2) emissions from fossil-fueled generating plants will not only increase capital costs but also impose significant performance penalties, challenging the competitiveness of new coal generation. Many locations worldwide lack suitable geology for CO2 storage, one of several factors expected to constrain CCS deployment.

This poses a question: Is technology available or in development that would enable power plants fueled solely by coal to operate so efficiently that a CO2 emission standard of 636 kg/MWh (1400 lb/MWh) or less could be met without partial CCS?

Based on high-level assessments described in a new white paper published by the Electric Power Research Institute (EPRI), the answer is a qualified "yes." The paper, Can Future Coal Power Plants Meet CO2 Emission Standards Without Carbon Capture and Storage (EPRI report 3002006770) is available at www.epri.com.

Current state-of-the-art coal-fired plants, based on operations at ultrasupercritical (USC) steam conditions above 593°C (1100°F), emit approximately 800 kg (1760 lb) CO2/MWh. Several U.S. states and a number of countries have announced or are considering similar restrictions on CO2 emissions from new coal-fired plants.

Except in China, existing and proposed government standards for CO2 emissions cannot be met solely by building an efficient coal power plant using current state-of-the-art USC technology. To achieve EPA's limit, the conventional wisdom is that more than 20% of a new U.S. coal plant's CO2 emissions would have to be captured for long-term sequestration. Carbon capture with underground storage has been deemed by EPA as the "best system of emission reduction," but applications are constrained by technology, policy, and market factors. Power plant developers evaluating possible investments are reluctant to consider new coal generation due to uncertainty, the cost of capture, and the difficulty in finding a suitable storage location.

Some industry executives are beginning to wonder if an easier path to regulatory compliance might be found through advanced coal technology. The answer is clear: Without CCS, a CO2 limit of 636 kg/MWh (1400 lb/MWh) or lower can only be achieved by increasing the thermal efficiency of the energy conversion processes involved in generating electricity from coal—a challenge more easily stated than accomplished. EPRI found:

- Even with steam temperatures exceeding 800°C (1500°F)—some 200°C (360°F) higher than those currently achievable—USC coal plants based on the conventional Rankine steam-electric cycle alone are not capable of meeting the standard.

- USC plants used in high-efficiency combined heat-and-power applications are capable of meeting the standard—but only at sites with "thermal hosts" capable of using large volumes of steam.

- Gasifying coal then firing the synthesis gas in a conventional combined-cycle configuration can meet the standard—but only for certain types of gasifiers, and only when the integrated plant is fueled by high-quality coal.

- Assuming further technological progress, coal gasification provides multiple pathways for achieving the standard, including gasifiers integrated with solid oxide fuel cells; with combined-cycle plants having firing temperatures for the combustion turbine approaching 1700°C (3100°F); or with novel cycle designs.

Power producers interested in new coal plants could explore potential thermal hosts for cogeneration projects or the economics of gasifying and firing high-quality coal. Greater public-private investment in research and development (R&D) is needed to accelerate commercialization of gasification-based cycles and component technologies.

Taking a closer look at coal generation technologies

Rankine Cycle Plants with Higher Steam Temperatures

The overwhelming majority of coal-fired power plants are based on the Rankine cycle, in which high-pressure steam is raised from the heat released while burning pulverized coal. The steam is used to spin a turbine, which in turn drives an electric generator. The basic thermodynamics of the Rankine cycle (and in fact of any heat engine) dictate that efficiency can be improved by increasing the temperature ratio of the hottest and coldest points in the cycle.

For the Rankine cycle, this means increasing the temperature of the steam entering the turbine and/or decreasing the temperature in the condenser at the turbine exit. For 60 years, there was a steady advance in steam temperatures from 260°C (500°F) to 650°C (1200°F); however, the power industry has reached a limit in the capabilities of ferritic-based steels.

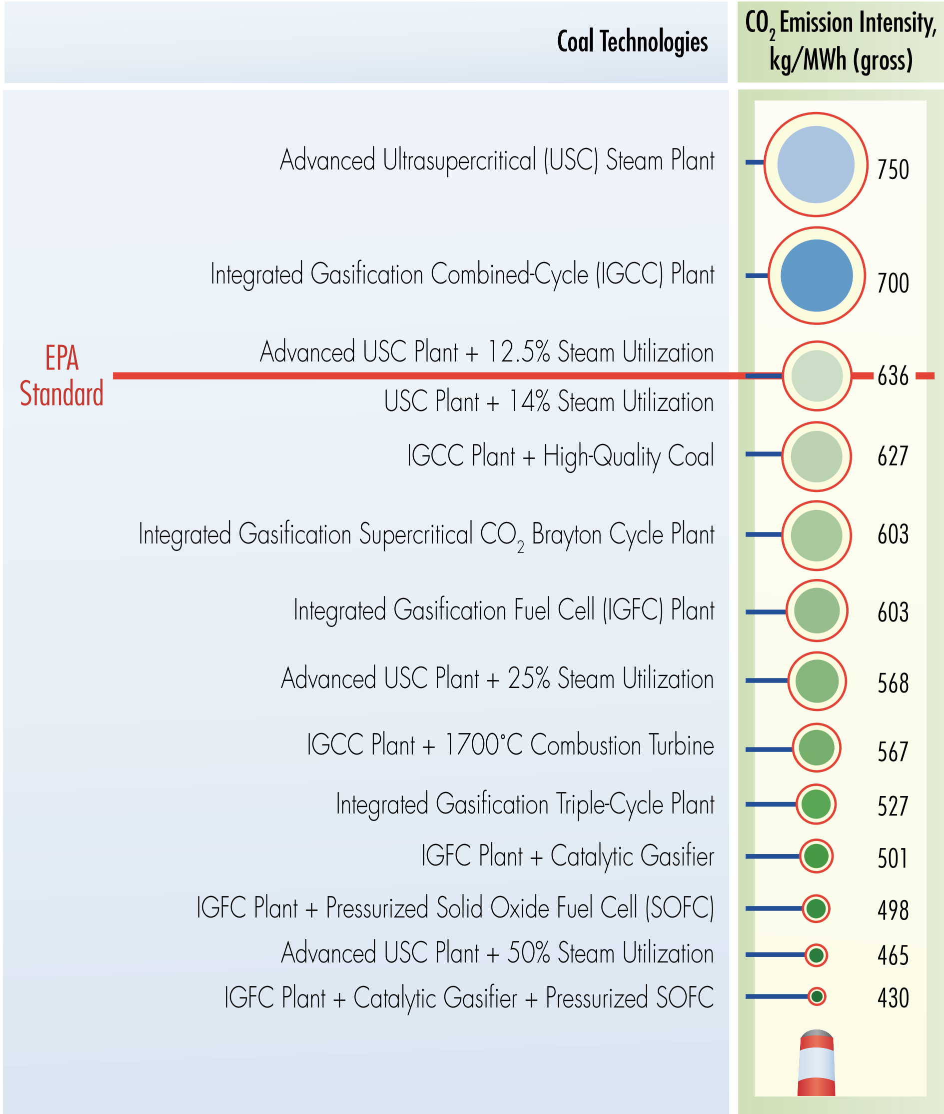
Since 2001, a U.S. Department of Energy (DOE)-funded R&D consortium has been pursuing advanced materials for coal-fired boilers and steam turbines, with EPRI serving as the technical lead. Materials other than ferritic steels must be used to increase the thermal efficiency of the Rankine cycle. In particular, nickel alloys show promise of allowing steam temperatures to rise to 760°C (1400°F). That would allow an increase in gross thermal efficiency of at least 10%, from the current ~41% for USC plants to ~45% for next-generation advanced USC plants.

This increase in efficiency would not be sufficient to meet EPA's standard, but deploying advanced Rankine cycles would significantly decrease the amount of CO2 that would have to be captured and stored in order to achieve compliance. And the possibility exists for materials to be developed that would allow Rankine cycle coal power plants to reach steam temperatures greater than 760°C (1400°F). However, EPRI has calculated a plant capable of meeting the EPA standard of 636 kg/MWh gross (1400 lb/MWh) would require steam temperatures around 1125°C (2050°F). This is well beyond current materials technology.

Combined Heat and Power Applications

Another way to increase the thermal efficiency of pulverized coal power plants is to utilize the input fuel's energy to produce both electric power and useful heat. Combined heat and power (CHP) or cogeneration (cogen) plants—as they are frequently called in Europe and the United States, respectively—can approach very high utilization rates. The technology is commercially mature. Examples of typical "thermal hosts" for the exported heat from CHP plants are oil refineries, food processing facilities, and central heating districts for commercial buildings, large hotels, hospitals, and university campuses. Because exported heat can displace the burning of fossil fuel that would otherwise have been used to generate heat at the thermal host's location, EPA's standard offers CHP plants full credit for any heat that is exported and put to good use.

To assess the CO2 emission intensity of cogen applications based on EPA's formula, EPRI explored four CHP cases, one based on



Low CO2 technology options for meeting EPA emission perfromance standards without CCS

current USC steam conditions and the others starting from an advanced USC plant design with a main steam pressure of 276 bar (4000 psi) and main and reheat steam temperature of 760°C (1400°F). EPA's standard could be achieved by a new cogen plant based on current state-of-the-art ultrasupercritical (USC) technology incorporating at least 14% steam extraction and utilization. The limit also could be met by using at least 12.5% of the steam from an advanced USC plant. Lower standards set by U.S. states and other nations could be achieved based on higher CHP fractions.

However, scale is an issue. An advanced USC plant producing nominally 750 MW of net electric power with 12.5% steam extraction would require a thermal load of approximately 150 MW—about 50 kg/s (0.4 million lb/h) of steam at 4.7 bara (68 psia) and 367°C (693°F). Because only a modest number of thermal loads sized at 150 MW or larger are likely to be available, smaller advanced USC plants operating in CHP mode may represent a more widely applicable approach.

Coal Gasification Integrated with Combined Cycles

Gasifying coal to produce a synthesis gas (syngas) opens up additional potential pathways for meeting CO2 emission limits without CCS. Syngas, consisting predominantly of carbon monoxide (CO) and gaseous hydrogen (H2) fuel, can be turned into electricity by many methods. One is through a combined-cycle plant, like today's workhorse natural gas generators, which offer gross thermal efficiency of 50-54% on an HHV basis (typically, their efficiency is reported at 55-60% on an LHV basis).

The coal is converted to syngas, which is cooled to achieve temperatures that combustion turbine materials can accommodate. Contaminants, specifically sulfur species and ash mineral content, are removed. Clean syngas is then fired in the open Brayton cycle combustion turbine. The turbine exhaust is fed to the Rankine cycle HRSG, which also receives steam from the syngas cooler.

State-of-the-art IGCC units have thermal efficiencies based on net power output that are similar to those of state-of-the-art, standalone Rankine cycle coal power plants, offering significantly lower gross CO2 emission intensities. However, the auxiliary power consumption of IGCCs is greater—an important consideration when gross CO2 emission intensity is the parameter of merit.

While existing IGCC technology could meet EPA's standard under certain conditions, more stringent limits in the UK, Canada, and some U.S. states could not be achieved. IGCC efficiency gains (and resulting reductions CO2 emissions intensity) can be realized by increasing the firing temperature of the combustion turbine. EPRI's 2011 IGCC R&D roadmap concluded that going from today's range of 1370°C–1430°C (2500°F–2600°F) to 1700°C (3100°F) would decrease heat rate by 16%. Japan has a national R&D program pursuing a combustion turbine with 1700°C (3100°F) firing temperature. The focus is on advancing the necessary materials technology by developing key components, as steps toward creating a complete turbine. The Pratt & Whitney jet engine used in the U.S. F-35 "Joint Strike Fighter" operates at 1982°C (3600°F). The technical feasibility of a firing temperature approaching 1700°C (3100°F) thus has been established; the timeline for commercial deployment of HTCTs optimized for IGCC operation is uncertain but appears to be about a decade away.

Coal Gasification Integrated with Supercritical CO2 Brayton Cycles

Closed Brayton cycles using supercritical CO2 (SCO2) as the working fluid are being investigated by several organizations as a way to increase the thermal efficiency of advanced nuclear, solar, and fossil power plants. An early demonstration of this advanced cycle is under development for natural gas and concentrating solar plant applications; the SCO2 cycle can also be integrated with a coal gasifier. SCO2 is introduced to the burner to dilute the mixture because firing syngas in oxygen would result in temperatures above 2750°C (5000°F), far exceeding the level current turbine technology can tolerate. Recycling a large flow of CO2 moderates the firing temperature to 1150°C (2100°F).

The stream exiting the burner includes a small amount of water vapor but consists mostly of CO2. The ratio of recycled CO2 to that produced by combustion of the syngas is about 10:1. The flow is expanded in a turbine to drive a generator. The turbine exhaust, still at high temperature (>700°C or 1300°F), is directed to a large heat exchanger (recuperator), then cooled further to condense out the water vapor. The remaining flow, essentially all CO2, is raised up to high pressure (165 bar or 2400 psi), then preheated in the recuperator prior to reintroduction to the burner.

A 2014 EPRI report (3002003734) summarizes findings from an analysis of various syngas-fed oxy-fired SCO2 Brayton plant designs with 100% CCS. Various configurations offered increases ranging from >25% to >40% in net thermal efficiency relative to state-of-the-art IGCC plants with 90% CCS, providing CO2 emission intensities below the U.S. EPA target.

Coal Gasification Integrated with Solid Oxide Fuel Cells

Fuel cells have long held the promise of higher-efficiency power generation based on natural gas, hydrogen fuel produced via the electrolysis of water, and other gaseous fuels. Combining a coal gasifier with a fuel cell offers similar opportunity.

In 2011, DOE's National Energy Technology Laboratory (NETL) issued an analysis of the projected performance of integrated gasification fuel cell (IGFC) power plants, in which solid oxide fuel cell (SOFC) technology essentially replaces the combustion turbine in IGCC designs. As with a conventional IGCC plant, the coal is converted to syngas, which is cooled to a level the SOFC can tolerate. The fuel cell can be thought of as a dry cell battery—but one in which the chemical ingredients are continuously refreshed rather than depleted as energy is produced. In the case of an SOFC, the ingredients are syngas, which is fed to the anode side of the cell, and oxygen, which is supplied by blowing air into the cathode side of the cell. This enables an electrochemical reaction that produces heat and induces direct current, which is converted to grid-compliant alternating current via an inverter.

The chemical reaction in the SOFC does not fully consume the syngas. Any remaining CO and H2 are mixed with hot air leaving the cathode and then combusted in a burner. The HRSG applies the combustion exhaust from the burner to raise steam, which is mixed with steam produced in the syngas cooler to drive a steam turbine. The SOFC can operate at atmospheric pressure, in which case the auxiliary power required to blow the air through the cathode is rather modest, or at elevated pressure, which increases gross energy output. Pressurized SOFCs can employ an electric compressor or draw on an expander driven by combustion exhaust to push the air into the cathode.

EPA's standard could be achieved using a conventional gasifier with an SOFC operating at atmospheric pressure. More stringent standards could be met by using a pressurized SOFC or catalytic gasifier. An IGFC plant design operating on CH4-enriched syngas and at elevated pressure would have a CO2 emission intensity of 430 kg/MWh (946 lb/MWh). SOFCs are still at an early stage in the development cycle. A recent peer review of DOE's SOFC R&D program indicated that the largest high-temperature SOFC module constructed to date has a rated capacity of 60 kW of power and has operated for only 1600 hours.20 According to EPRI's analysis, megawatt-scale modules are not expected until after 2020.

Coal Gasification Integrated with Triple Cycles

University of Tokyo professor Dr. Shozo Kaneko, among others, has promoted the concept of integrating SOFCs with conventional combined-cycle plant configurations to create "triple-cycle" plants that could be fueled by natural gas, coal-derived syngas, or other sources. The potential thermal efficiency advantage of IGTC over IGFC designs is that hotter turbine inlet temperatures can be achieved by having the SOFC feed a combustion turbine.

To conduct an initial assessment of this design, EPRI developed a simplified IGTC model and simulated performance based on a conventional coal gasifier, a pressurized SOFC, and a G-class turbine with a 1500°C (2732°F) firing temperature. Results indicate a possible net thermal efficiency of greater than 51% (HHV basis) and CO2 emission intensity of approximately 527 kg/MWh gross (1159 lb/MWh), sufficient to achieve the EPA standard. Room for improvement in IGTC performance—to achieve even lower limits—appears to exist through design optimization and perhaps eventually through the achievement of a 1700°C (3100°F) turbine firing temperature. SOFC technology remains the limiting factor.

The triple-cycle design has a higher CO_2 emission intensity than the IGFC plant with a pressurized SOFC. However, this is an artifact of both underlying design assumptions and the EPA standard's basis on gross power output. The pressurized IGFC configuration employs an electric compressor to deliver air to the cathode, increasing gross output and thus artificially reducing gross emission intensity. The IGTC configuration simulated by EPRI instead pressurizes the SOFC via an air compressor with a direct mechanical connection to the expander in the combustion turbine, improving thermal efficiency. Consequently, IGTC plants are expected to be better performers relative to CO_2 emission standards based on net power output.

Conclusions and next steps

Yes, technology has been identified that would enable new coal power plants to operate so efficiently that a CO_2 emission standard of 636 kg/MWh (1400 lb/MWh) could be met without partial CCS. However, among all of the options firing sub-bituminous coal considered in EPRI's analysis, none with potential to meet the standard are commercially available, economically viable, and suitable for broad deployment.

To help expand the available options for generating electricity with coal while achieving CO_2 emission standards, additional public-private R&D investment is needed to accelerate the commercialization of SOFC technologies, higher-temperature turbines capable of operating on coal-derived syngas, and SCO_2 Brayton cycles. National R&D programs in the United States, Japan, and elsewhere are making progress. Greater resources and increased collaboration are recommended due to the challenges that are facing CCS deployment.

In addition, a study of existing and potential future thermal hosts capable of accommodating large volumes of steam in the United States and other countries is recommended. This would help determine the extent to which the CHP option may be available for building new coal-fired power plants and achieving CO_2 emission standards without the need for partial CCS.

More information

The full White Paper is available from the Electric Power Research Institute:

www.epri.com

Low carbon electricity most cost effective for UK

A low-carbon electricity supply is the most cost-effective way to meet the need for more generation in the 2020s given the UK's climate change commitments, says a Committee on Climate Change report.

In a new report, 'Power sector scenarios for the fifth carbon budget', the Committee sets out a range of future options to reduce the UK's emissions from electricity in 2030. Low-carbon options in the power sector are important to support emissions reduction in other sectors, such as transport and heating, as well as to reduce emissions from the power sector itself.

The new power sector scenarios seek to balance issues of affordability, security of supply and decarbonisation. They indicate different ways, rather than one prescriptive path, through which this balance can be achieved consistent with UK climate change targets.

The report sets out new analysis the CCC will take into account when it provides its advice to Government on the fifth carbon budget on 26 November 2015.

Assessing the UK's obligations under the Climate Change Act, and the requirement to ensure competitiveness, affordability and security of the UK power supply, the Committee finds:

• Investments to 2020 are largely committed already. These will reduce power sector carbon intensity from around 450 gCO_2/kWh today to around 200-250 gCO_2/kWh. Households are currently paying around £45 a year on their electricity bill to support this investment, and will pay around £105 by 2020 (of a total bill of around £500).

• New investment in power generation will be needed in the 2020s to replace retiring coal and nuclear power and to meet future increases in energy demand.

• Several low-carbon sources of power are likely to be cost competitive with new gas-fired generation facing a carbon price during the 2020s. Mature options, like onshore wind and solar, are at that stage already. Less mature options, like carbon capture and storage (CCS) and offshore wind, will require continued support into the 2020s if they are to reach maturity. These both represent good value investments for a society committed to climate targets.

• Balancing all factors, power sector emissions of below 100 gCO_2/kWh are an appropriate aim for 2030. The range of scenarios examined suggest that power sector emissions towards the upper end of the carbon intensity range of 50-100 gCO_2/kWh, previously identified as being suitable for 2030, are appropriate. Emissions would be around 55 $MtCO_2$ lower than if investment in the 2020s was focused solely on gas-fired generation.

• There will be additional costs on bills from low-carbon investment in the 2020s. Under central assumptions, the impact on annual household bills of supporting low-carbon investment would increase from around £105 in 2020 to a peak of around £120 in 2030.

• Increasing system flexibility will be important to ensure security of supply at lowest cost. Developing a more flexible electricity system with responsive demand, interconnection to other markets and more electricity storage will support security of supply, reduce emissions and reduce costs.

www.theccc.org.uk

Projects and policy news

ZEP plan for enabling CCS in Europe

www.zeroemissionsplatform.eu

The Zero Emissions Platform (ZEP) has released its Executable Plan for enabling CCS in Europe.

The European Commission's SET-plan identifies Carbon Capture and Storage as one of its ten research priorities towards cost-effectively achieving a fundamental transformation of Europe's energy system.

To achieve CCS at commercial scale, the EU requires strong political direction, the right funding mechanisms and a robust investment environment. In this context, ZEP's plan lays out concrete steps for delivering CCS through existing policies and public financing opportunities and introduces a business model that will ensure a strong case for investing in CCS.

Dr Graeme Sweeney, Chairman of the Zero Emissions Platform, said, "The logic that emitting CO2 is cheaper than capturing and storing it needs to be disrupted. We have a proven technology available but now must remove the remaining obstacles to make a sound business case for infrastructure development. This plan introduces European “Market Makers”, either state-owned or regulated private entities, as efficient and cost-effective mechanisms for accelerating the deployment of CCS by creating flexibility in the market. These can be the catalyst for translating intentions into actions."

Dr Luke Warren, Chief Executive of the CCSA, commented, “This report represents another important step towards re-injecting much-needed momentum into CCS in Europe. ZEP has rightly identified the importance of ensuring that CCS projects in development get over the finish line – this will be vital in the UK where the Government will soon be making critical decisions on the next steps for the White Rose and Peterhead CCS competition projects."

"As the Plan highlights, timely development of transport & storage infrastructure will be key to laying the foundations for CCS clusters across Europe. European funding has already helped to support the early development of transport and storage infrastructure in the Yorkshire and Humber region of the UK – through a grant of Euro 180 million to the Don Valley power project – and we anticipate further EU support for project development under the proposed EU Innovation Fund."

"Alongside the EU institutions, the Plan also emphasises the key role that EU Member States will need to play in enabling the cost-effective deployment of CCS infrastructure. In the UK the CCSA has called on Government to establish grant funding of up to £100 million to bring forward sufficient CO2 storage capacity to support the deployment of CCS in the North Sea over the next decade."

"With the countdown to the Paris COP meeting well and truly underway, and countries such as the US coming forward with ambitious CCS programmes, it is now time for the European Commission and EU Member States to rekindle the CCS fire and demonstrate to the world that CCS is a vital part of the EU's climate and energy strategy."

Drax pulls out of White Rose CCS project

www.whiteroseccs.co.uk

Drax will complete FEED studies but not invest further in the White Rose CCS project because of reduced renewable subsidies.

Drax said it remained committed to fulfilling its current work on the feasibility and technology development of the project, but would not be investing further and will withdraw as a partner of Capture Power Ltd, the developer of the White Rose CCS project.

However it will continue to make the site owned by Drax, along with the infrastructure at the Power Plant, available for the project to be built.

Drax Group Operations Director, and Capture Power Board Director, Pete Emery said the decision was based purely on, "a drastically different financial and regulatory environment and we must put the interests of the business and our shareholders first."

Capture Power said it was still committed to the delivery of the project and will continue to work constructively with Drax on land, site services and shared infrastructure aspects to support the Project's delivery.

The announcement puts in doubt whether the White Rose Project can continue to participate in the UK Goverment's £1 billion CCS competition.

UK Government awards £1.7M to CCS projects

decc.gov.uk

£1.7 million was awarded to three CCS projects as part of Phase 4 of the Government's Energy Entrepreneurs Fund.

The funding will support the development and demonstration of CCS technologies to support cost reductions and innovation. In total £4.5 million was awarded to 14 companies to support development and demonstration of technologies across the areas of energy efficiency, power generation, heat and electricity storage as well as CCS.

The three CCS-related projects are:

• Carbon Clean Solutions Ltd (CCS Ltd) have developed a range of solvents to remove CO2 from flue gases from fossil fuel fired power stations and industrial processes. The project aims to compare the performance of different solvents, to quantify the potential in reduction of capital cost and operating cost for capturing CO2 as these new solvents require less energy and have improved environmental performance than the industry bench mark. The project will be led by CCS Ltd in collaboration with Newcastle University and University of Hull.

• C-Capture Ltd (C-CL) will be screening amine-free solvents that have reduced toxicity, environmental impact and corrosion characteristics, for suitability and scaling up for use in industry. The results will be used in licensing negotiations with manufacturers of CCS plant and chemicals.

• FET Engineering Ltd will be advancing their PureStream Project with the aim of making the PureStream technology (a proven electro-chemical process) available for commercial deployment from 2017 across a range of carbon, and other greenhouse gases emitters, both small and large in scale. The PureStream technology can also be retrofitted into existing infrastructures, is a lower cost and more environmentally friendly solution to carbon capture than the current CCS technologies under development.

Saudi Aramco hosts CSLF ministerial forum

www.cslforum.org

Saudi Aramco welcomed global energy ministers, officials and experts from the Carbon Sequestration Leadership Forum (CSLF) to its Dhahran headquarters.

H.E. Ali I. Al-Naimi, Minister of Petroleum and Mineral Resources, Saudi Arabia and CSLF Ministerial Co-Chair hosted an international delegation at the 8th CSLF Ministerial Meeting

The CSLF is a Ministerial-level international climate change initiative focused on the development of improved cost-effective technologies for the separation and capture of carbon dioxide (CO2) for its transport, utilization and long-term safe storage. The CSLF is currently comprised of 24 members, including 23 countries and the European Commission. Its member countries represent over 3.5 billion people or approximately 60% of the world's population. The CSLF held its sixth Ministerial Conference in Riyadh, Saudi Arabia from November 1- 4.

H.E. Ali I. Al-Naimi, Minister of Petroleum and Mineral Resources, Saudi Arabia and CSLF Ministerial Co-Chair hosted a delegation that included Dr. Ernest Moniz, Secretary of Energy, United States and CSLF Ministerial Chair, and Ministers and ministerial representatives from Australia, Canada, China, the Czech Republic, France, Korea, and the United Kingdom.

H.E. Ali I. Al-Naimi, Minister of Petroleum and Mineral Resources, Saudi Arabia said: "We are here today because we are united in a common cause. We want to tackle climate change and we know that technology holds the key. We also appreciate that it is only by working together that these challenges will be overcome. From what I have witnessed these past few days at CSLF, I am confident that we are on the right track. That said, there is a lot more hard work ahead. As today's visit to Saudi Aramco helps demonstrate, Saudi Arabia is playing its part. Globally, it is gratifying to me to hear that so many nations are taking positive steps forward in terms of CSLF."

Amin H. Nasser, President and CEO, Saudi Aramco, who welcomed the delegation, said: "The key to unlocking the full potential of CCS is advancing technology that will turn it into a more viable option. To complement our existing energy efficiency programs, Saudi Aramco has piloted a CCS project to contribute to the scientific knowledge associated with this technology."

Saudi Aramco launched Saudi Arabia's first carbon capture and storage pilot project in July 2015 at the 'Uthmaniyah field and Hawiyah facilities. The largest such project in the Middle East, it will inject 800,000 tons of CO2 every year. In addition, the company has invested in technology start-ups, including Novomer which develops catalysts capable of efficiently converting CO2 into products, such as polyurethane.

During the CSLF Forum in Riyadh, Saudi Aramco was recognized for a project that advances Oxy-Combustion technology which improves the combustion of difficult to burn liquid fuels while capturing CO2 at high rate and purity. This technology will capture CO2 emissions from power plants, refineries and industry at large.

Ahmad Al-Khowaiter, Chief Technology Officer, Saudi Aramco said: "This prestigious international recognition by CSLF reflects Saudi Aramco's technical leadership in addressing global challenges and our efforts in addressing climate change issues. Our Oxy-Combustion technology demonstration project shows promising results for further scale-up as a means to utilizing difficult to burn heavy residues for efficient power generation with the potential for 90% CO2 capture."

Southern Company and Korea Electric collaborate on CCS

www.southerncompany.com
www.kepco.co.kr

Southern Company subsidiary Southern Company Services and Korea Electric Power Corporation (KEPCO) will jointly market CCS technologies.

Through the agreement, the companies will jointly explore opportunities for these and other technologies in the U.S., the Republic of Korea and in developing nations.

Among the technologies to be evaluated is Transport Integrated Gasification (TRIG™), developed at Mississippi Power's Kemper County energy facility and marketed by Southern Company and KBR. The Kemper facility is designed to generate electricity using low-rank coal with resulting carbon emissions better than a similarly sized natural gas plant. At least 65 percent of the plant's carbon emissions are expected to be captured and repurposed through enhanced oil recovery.

The agreement also provides for the testing of KEPCO's carbon capture technologies at the U.S. Department of Energy's National Carbon Capture Center (NCCC) in Alabama, which is operated by Southern Company Services.

Aligned with efforts by the U.S. and Korea to cost-effectively reduce greenhouse gas emissions, the NCCC conducts research and development (R&D) to evaluate and advance emerging carbon capture technologies through integration with a coal-fired power plant and a pilot gasification facility.

CO2 Capture Project receives CSLF recognition

www.co2captureproject.org

The CCP (CO2 Capture Project) has received twofold international recognition for its pioneering work in CO2 capture and storage (CCS) from the Carbon Sequestration Leadership Forum (CSLF).

The Global Achievement Award was presented to the CCP Chair, Nigel Jenvey, by His Excellency, Ali Al-Naimi, Minister of Petroleum and Mineral Resources for the Kingdom of Saudi Arabia and Dr Ernie Moniz, United States Secretary of Energy at a dinner during the CSLF Ministerial meeting in Riyadh, Saudi Arabia on 4th November 2015.

The recognition of CCP4 follows earlier recognition for CCP from the CSLF for CCP's second and third phase of work since its formation in 2000.

In total the CSLF recognition comprised of:

• A Global Achievement Award for the third phase of the CCP program (CCP3 – 2009-2014), reflecting CCP's role as an exemplary model of scientific research that shares its learnings and insights in developing CCS technologies

• Recognized Project status for its current, fourth phase (CCP4 – 2014-2018), which aims to further advance CO2 capture and storage technologies and understanding for the oil and gas sector.

Now in its fifteenth year, the CCP is a partnership of major energy companies working together to develop pioneering CCS technology research and knowledge for potential application in the oil and gas industry. CCS has an important role to play in reducing emissions from power plants and heavy industrial processes such as oil and gas refining, gas processing and cement manufacture.

The CCP4 program aims to develop further research and understanding of CO2 capture solutions for gas processing, refineries, heavy oil extraction and upgrading, and natural gas power generation.

With regard to CO2 storage, the CCP4 program will continue to demonstrate safe and secure geological containment through field-based monitoring and the development of robust intervention protocols.

Call for a single UK CCS organisation

www.sccs.org.uk

Carbon capture and storage could move along much faster in the UK if there was a single government organisation responsible for driving it, says Lord Oxburgh

Carbon capture and storage in the UK is close to being stalled, because there isn't any single organisation responsible for making sure it happens, said Lord Oxburgh, honorary president of the Carbon Capture and Storage Association (CCSA), a former chairman of Shell and Rector of Imperial College London.

He was speaking at a Scottish Carbon Capture and Storage event in the House of Lords, London on September 15, to mark the release of its "CO2MultiStore" in-depth study into CO2 storage in the North Sea.

"Coal companies, power companies, oil companies say this [CCS] s a good thing. But no organisation is responsible."

"Government is supportive, but doesn't take responsibility for [creating] structures that private industry can operate in. That framework is not there."

"We started [carbon capture] more than ten years ago. It took the US ten years to go from a standing start to getting a man on the moon. But CCS is not rocket science."

"If we put anything like the money and determination which went behind the [man on the moon] project, we would be there."works.

"The difficulty is putting together a story which any investor is willing to put money behind," he said.

"There are three components, capture, transport and storage. You can put transport and storage together, but the capture is something else."

"If you try to put money into transport and storage, if CO2 is not there, it is not a credible story," he said.

Similarly, if you make a business for carbon capture without a plan for transport and storage, it won't work for investors.

"You have to do the virtually impossible and put both together," he said. "Both are complex high capital intensive activities."

"Some organisation must take an active promotional view of this."

$20 million XPRIZE to convert CO2 into useful products

carbon.xprize.org

The $20M NRG COSIA Carbon XPRIZE is a competition to address CO2 emissions from fossil fuels.

Teams are challenged to develop breakthrough technologies that convert the most CO2 into one or more products with the highest net value. Sponsored by NRG and COSIA, the 4½ year competition will include two tracks, with the new technologies tested at either a coal power plant or a natural gas facility.

"We are living in an age of unprecedented technological progress and prosperity driven by energy," said Diamandis. "Yet, most of this energy comes from burning fossil fuels, a leading contributor to climate change. We are embarking on one urgent step in XPRIZE's energy roadmap of incentivizing a clean and positive energy future that addresses a suite of Grand Challenges."

The Carbon XPRIZE will incentivize breakthrough technologies that convert CO2 into a product or suite of products such as: alternative cement, concrete, and other building materials; chemicals used to manufacture a variety of industrial and consumer goods; low-carbon transportation fuels; and possibly new products altogether.

XPRIZE will appoint a judging panel to evaluate the various technologies and approaches developed by teams during the competition. XPRIZE will also appoint a third-party Scientific Advisory Board of experts available to advise on a variety of approaches to CO2 conversion.

"We know that CO2 emissions contribute to climate change so we're continually working to improve our environmental performance in the oil sands," said Dan Wicklum, COSIA chief executive. "This competition will be a catalyst to accelerate our progress towards a cleaner global energy future by converting CO2 emissions into valuable products. A team may win the money, but our energy future will win the prize."

CCS in Rotterdam – ROAD in competition with Peterhead?

Carbon Capture Journal attended the 8th Dutch CCS Symposium in Rotterdam on October 16th – and learned that the Dutch 'ROAD' CCS project is now on a similar schedule to the UK's Peterhead and White Rose. Could they be in competition? www.co2-cato.org

By Karl Jeffery

The Rotterdam Storage and Capture Demonstation Project, better known as 'ROAD' (or Rotterdam Opslag en Afvang Demonstratieproject), could be going ahead after all.

There was lots to be excited about at the 8th Dutch CCS Symposium in Rotterdam on October 16, organised by the Dutch National CCS research program CATO, but this was perhaps the most exciting news.

At the previous event in June 2014, we learned that ROAD was 'essentially mothballed' with the project team on the hunt for new financing.

Since then, the team have started exploring ways to reduce the storage costs, by looking for new storage sites with less drilling required.

They have also explored different ways to get the project started, perhaps by having an initial step of passing the CO2 onto local greenhouses to use as fertiliser, rather than starting with both capture and storage together.

The ROAD team now plans to resubmit permit applications in early 2016, planning for a final investment decision sometime in 2016, for the plant to be in operation by 2019, said Onno Tillema, managing director of ROAD.

We heard that Norway recognises that as a small country it needs to partner with other countries in CCS research. But it wants to build its own CCS demonstration plant (as well as co-operating with ROAD), and would like it to be operating by around 2020.

Coincidentally, this puts ROAD on a very similar timescale to the two UK projects White Rose and Peterhead – where the UK government is hoping for a final investment decision in early 2016 for operation in the end of 2020.

The audience at the 8th Dutch CCS Symposium in Rotterdam on October 16, organised by the Dutch National CCS research program CATO (Images ©Floris Scheplitz and CATO)

We heard that Norway recognises that as a small country it needs to partner with other countries in CCS research. But it wants to build its own CCS demonstration plant (rather than help to finance ROAD), and would like it to be operating by around 2020.

So we have something which hardly anyone would have predicted 10 years ago – the first CCS projects in Europe on a very similar timescale. Do we have a competition to see who gets started first?

Our technical readers may groan at the idea of a competition as a motivating force – it may remind you of what you dislike most about your working environment, or remind you of school.

But whether these projects get started mainly depends on decisions made by our political readers – who may be far more motivated by competition.

Stan Dessens, chair of CATO's Executive Board, said that this competition "could be an enormous stimulus", and he would like CATO to award a prize to the first project to get funded.

Mr Dessens knows very well how government people think – he is a former Director General of Law enforcement with the Dutch Ministry of Justice, and Director General for Energy with Ministry of Economic Affairs.

In his opening remarks, Mr Dessens observed that the Netherlands is expecting 16 per cent of energy to come from renewables by 2023, 30 per cent by 2030, 40 per cent by 2040 and 50 per cent by 2050, so by the end of the century all energy is supplied by renewable energy.

"I think that is a bit optimistic," he said. For people who think renewables can grow fast enough, "I congratulate them".

"But for those who are more pessimistic, I offer a bridge, it is CCS. It is quite a simple philosophy."

In his closing remarks to the conference, Mr Dessens said that the day's presentations had changed his mind about carbon capture and storage."

"I was rather pessimistic until now. But this afternoon I've had some positive signals."

"What type of feeling do we go home with? Do we say, 'it's positive'? Or do we really say 'it's positive'?"

"The signal of ROAD getting a final investment decision, to my impression, it became more serious."

The conference honoured Daniel Jansen from Dutch Research organisation ECN, and Henk Pagnier of Dutch research organisation TNO, who are retiring this year. They have both done a great deal to bring together the different disciplines of CO_2 capture and storage, Mr Dessens said.

ROAD

The team behind Dutch carbon capture project ROAD is now planning to restart permit applications early 2016, planning to make a final investment decision "sometime in 2016", with a build phase ending in 2019, revealed Onno Tillema, managing director of ROAD, speaking at the conference.

ROAD stands for Rotterdam Opslag en Afvang Demonstratieproject, which means Rotterdam Storage and Capture Demonstation Project.

One major new step is to connect ROAD with the "OCAP" CO_2 distribution network, supplying to industrial greenhouses, operated by gas company Linde. OCAP means "Organic CO_2 for Assimilation by Plants."

The Westland region of the Netherlands has enormous greenhouses used for growing flowers and vegetables, which require heating in winter, and CO_2 as a fertiliser. Currently both of these are provided by combusting gas.

Using captured CO_2 as a fertiliser in greenhouses is controversial, because the CO_2 ultimately ends up in the atmosphere. If it is absorbed by the plants, they will eventually rot and give off biogas.

"I was rather pessimistic until now. But this afternoon I've had some positive signals" - Stan Dessens, chair of CATO's Executive Board

But this argument is arguably mitigated if you consider that the greenhouses would otherwise have required a supply of CO_2 and heat made especially for them, and they can find an alternative supply of heat from a waste power plant (see next section).

Mr Tillema takes solace from an old Chinese proverb "it is better to take many small steps in the right direction than to make a great leap forward only to stumble backward.

The world may be expecting 7bn tonnes a year of CO_2 storage by 2050 (equivalent to 20% of total 2013 emissions), but in order to get there, you need to start somewhere.

"The beginning of the project is the most expensive part. If you can make saving at the beginning you can make the project fly," Mr Tillema said.

Rotterdam is in a terrific location for CCS, with offshore gas fields for storing CO_2, coal power plants, refineries and chemical plants creating CO_2 in the Maasvlakte, and heavy industry in Antwerp and Germany close by and accessible by water, so CO_2 can be transported in by ship, he said.

Getting to this point

In 2014, the engineering for ROAD had been finalised, permits were acquired and contracts were signed. The problem was money.

The original plan was that capital (construction) costs would be paid by government grants, and operations costs would be covered by sale of carbon credits under the Emission Trading Scheme (ETS).

Final investment decision on ROAD in 2016 - Onno Tillema, managing director of ROAD

But because the ETS price is lower than expected, it could not cover the operations costs, and without funding for operations, the plant could be built, he said.

Over the past year the ROAD team has explored alternative funding, including re-allocating EU European Energy Programme for Recovery (EEPR) funds, finding private investment, finding money from the second round of EU's "NER 300" scheme, and the EU Horizon 2020 scheme. "We didn't succeed with private investors, but we came close," he said.

The ROAD team put a great deal of effort in applying for funding under the NER 300 scheme, including compiling four boxes of documents, but in the end decided not to submit for it.

The Horizon 2020 scheme would only provide assistance once the project was built, so there was a chicken and egg situation, in that the ROAD team needed the commitment of operational financing before the plant could be built.

The ROAD team spent time looking at other capture technologies, but in the end came to the conclusion the original technology (solvent absorption) is the right one.

However it may be able to find a cheaper storage location, although this is not yet finalised. The location previously planned had "expensive drilling," he said.

By reducing or eliminating storage costs from the initial budget, and with a contribution from OCAP to operational costs, it can start realising the project, he said.

Once the plant has been built, then an application can be made for operational funding from Horizon 2020.

Rotterdam policy

Maarten de Hoog, Director of Port and Industry at DCMR (the environmental protection agency of Rotterdam) is keen to make Rotterdam a world centre for carbon capture and storage.

In 2007, DCMR announced that it expected the Rotterdam region to emit 46m tonnes of CO_2 in 2025, if it did not put a CO_2 abatement plan in place. It planned to use CCS to reduce this to 12m tonnes.

"Greenpeace say, 'if we promote CO2, do we also promote coal powered plants?' That hindered us." - Maarten de Hoog, Director of Port and Industry at DCMR (the environmental protection agency of Rotterdam)

"We all know, we did not realise this ambition," he said, speaking at the conference.

"Today the CO_2 emissions of Rotterdam are more or less 30m tonnes a year. We did not get projected growth but we did not get a reduction."

Emissions showed a small increase in 2014, due to a coal fired power plant coming on stream.

One reason for the lack of CCS progress is the low sense of urgency, he said, something he hopes the November international climate discussions in Paris will help to change.

Another reason for lack of CCS progress is the high cost of carbon capture and storage, although it is still lower than with solar. "It's a huge investment from the private sector," he said.

Another problem is lack of support from environmental organisations. "Greenpeace say, 'if we promote CO_2, do we also promote coal powered plants?' That hindered us."

There are local objections, illustrated with the Barendrecht CCS project, which aimed to store CCS beneath a residential area, and was cancelled. "People had a lot of questions, we didn't have the right answers," he sai.d

A further difficulty is the low CO_2 price. "[Once], we were talking Euro 30-40. Now we are talking 16 euro in 2025. That's much too low."

Another obstacle is that policymakers tend to look at CCS as a single issue, rather than as an integral part of a climate policy.

CCS is seen by many as a 'five past 12' measure – something to implement as a last resort, he said.

Port heat and greenhouses

DCMR is developing a pipeline infrastructure around Rotterdam for sharing port heat, with heat generated from a waste incinerator, to heat a fluid which flows around the port. The heat will be available for various industrial uses, so companies do not have to generate heat themselves.

This heat could be used to heat greenhouses in the Westland region. The greenhouses currently burn gas during the winter just for heating and providing CO_2 for fertiliser.

There could be a law requiring greenhouse operators to use port heat rather than producing it themselves, if the port heat is available, he said.

At some point in the future, carbon capture and storage could become 'best available technology', which means there could be legal requirements to use it.

Anita van den Ende

Anita van den Ende, Director Climate, Air and Noise, and Deputy Director General for Environment and International, with the Dutch Ministry of Infrastructure and the Environment, said that a lot of challenges with carbon capture are more to do with sociology than technology.

An example is the aborted Barendrecht carbon capture project. "Barendrecht was a really difficult period for CCS," she said. "Never forget you have to include all stakeholders."

Ms van den Ende was previously Director of Competition and Consumers

Ministry of Economic Affairs so has a background in both economics and environment.

To speed up CCS implementation, "we have to keep trying to find finances for [Dutch CCS project] ROAD and see that Europe helps us," she said.

"We see people in Germany are really looking at what we are doing, to see if they can help us."

"Barendrecht was a really difficult period for CCS, Never forget you have to include all stakeholders" - Anita van den Ende, Director Climate, Air and Noise, and Deputy Director General for Environment and International, with the Dutch Ministry of Infrastructure and the Environment

Shell

Tim Bertels, global CCS portfolio manager with Shell, said that the critical success factors in a CCS project are a license to operate (including with government support, industry ability, and society support).

Also the ability to build with confidence (which means the right legislation, liability agreements, early adopter benefits, trust and certainty between stakeholders); and the ability to replicate learning and share knowledge, he said.

On CCS in general, "I think there's more reason to be optimistic than 1 year or 2 years ago," he said.

CCS still has a lot of catching up to do with renewable energy, he said, citing Bloomberg data that $20bn has been spent so far on CCS, but $1929bn has been spent on renewable energy.

Shell is actually involved in five CCS demonstration plants.

It is a joint venture partner in Norway's "Technology Centre Mongstad" project to test CO_2 capture technology.

It operates the Quest Carbon Capture Project in Alberta, Canada. This facility uses amines to capture CO_2 from a mixture of CO_2 and hydrogen generated from steam reforming natural gas. The CO_2 is liquefied and sent to oilfields for enhanced oil recovery, and the hydrogen is used to 'upgrade' heavy oil into lighter oils. The plant is scheduled for start-up in November 2015).

Shell's carbon capture technology subsidiary Cansolv is used in the Boundary Dam project, also in Canada, the first large scale carbon capture and storage project in the world.

Shell is a major partner in the UK's Peterhead project, to develop the world's first large scale gas carbon capture and storage project. The Peterhead project is aiming for a final go-ahead decision in the first half of 2016, planned to be operational by 2020. At the time of the conference, the Front End Engineering and Design (FEED) was completed and Shell was evaluating bids from contractors to build it.

"I think there's more reason to be optimistic than 1 year or 2 years ago" - Tim Bertels, global CCS portfolio manager with Shell

Shell is also a partner in Australia's Gorgon project, which will produce gas containing 15 per cent CO_2, and strip out and inject the CO_2 underground, starting in 2017.

Some governments have provided Shell with 'early adopter' benefits, such as in Canada the company gets credits for the CO_2 it stores.

Some countries have 'innovation funds' available, including the UK and Alberta.

The EU's "NER" scheme "has been too limited, too many conditions perhaps," he said.

Gassnova

Norway is keen to have a full scale demonstration plant operating by around 2020, said Hans Jörg Fell, Chief Research Officer for Gassnova, an organisation with a mandate to "facilitate the Norwegian State's participation in carbon capture and storage (CCS) projects so as to provide maximum benefit for the State or State-owned entities."

He is also manager of the secretariat of the CLIMIT programme, the Norwegian state programme for research, development and demonstration of CCS technologies.

Norway has a bilateral agreement with the Netherlands to work together on CCS research under the 'CLIMIT-CATO' program. Norway acknowledges that as a small country, it makes sense to work together with other countries.

Norway is keen to have a full scale demonstration plant operating by around 2020 - Hans Jörg Fell, Chief Research Officer for Gassnova

Gassnova has a 75% ownership of Norway's Technology Centre Mongstad project, which tests carbon capture technology. This project is essential to verify that the technology works, more than is possible using a simulator, he said. It has also checked the emissions to air from carbon capture solvents, and the financial costs of building and running a plant.

The CLIMIT scheme is also funding a research project to use a palladium membrane to separate hydrogen from CO_2 (formed from steam reforming of natural gas). The technology is owned and also partly funded by Reinertsen and research is done by Norwegian research organisation SINTEF.

There is a NOK 300m research project called 'SOLVit' involving Aker Clean Carbon, SINTEF and The Norwegian University of Science and Technology, and a carbon capture project for cement at the Norcem cement plant at Brevik, Norway, also run by Aker Clean Carbon.

CO_2 to make sodium bicarbonate

This is a very interesting project – using CO_2 captured from the flue gas of a waste incineration plant to 'upgrade' sodium carbonate to sodium bicarbonate, which can then be used to remove dangerous impurities from the flue gas, such as hydrogen chloride and sulphur dioxide.

A very interesting CO_2 utilisation project is underway at the waste incinerator company Twence. This process is developed by the Dutch R&D company Procede.

It was explained at a break-out session of the 8th Dutch CCS Symposium in Rotterdam on October 16, by Patrick Huttenhuis, senior process engineer with Procede.

A problem with waste incineration is that the flue gas can have high concentrations of hydrogen chloride and sulphur oxides, based on sulphur and chlorine components present in the waste. These may not be released into the atmosphere due to environmental regulations.

Twence operates a waste combustion plant which processes 650,000 tons of waste material a year.

There is an established technology for dealing with this impurities, to treat the flue gas with dry sodium bicarbonate ($NaHCO_3$). It reacts with acid components, like HCl, HF and SO_2 to form deposits which can easily be removed from the flue gas with a filter.

One example of these reactions is $2NaHCO_3 + SO_2 + 1/2\ O_2 > Na_2SO_4 + 2CO_2 + H_2O$.

So waste incineration plants buy large volumes of sodium bicarbonate. However, sodium bicarbonate can be made by reacting sodium carbonate with carbon dioxide. This could be considered as CO_2 'mineralisation'. 1 tonne of sodium carbonate reacts to form 1.6 tonnes of sodium bicarbonate – so less raw material is required to capture a certain amount of flue gas if carbonate instead of bicarbonate is used.

The reaction to produce bicarbonate is: $Na_2CO_3 + H_2O + CO_2 > 2NaHCO_3$.

For this innovative project a new carbon capture plant is installed, which uses a special designed solvent to take the CO_2 from the flue gas stream. The plant captures 2,000 tons of CO_2 per year.

The overall carbon cycle is for CO_2 to be captured from waste combustion, reacted with sodium carbonate to form sodium bicarbonate, reacted with impurities in the flue gas (hydrogen chloride and sulphur oxides),to form CO_2 again, which is then vented. But there is a net reduction in CO_2 venting, because without the carbon capture, you would have CO_2 venting from both the flue gas and the treatment of the hydrogen chloride and sulphur oxides.

CO2 utilisation

"CO2 utilisation" has evolved from being something of a thorn in the heels of CCS proponents, to something which might actually work, says Dutch energy consultant Hans Bolscher.

When Hans Bolscher was director of climate and industry with the Dutch Ministry of Environment in 2009 to 2010, he was often annoyed by people who said 'we don't need CCS, we can just convert the CO2 into minerals,' he admitted, speaking in a break-out session of the 8th Dutch CCS Symposium in Rotterdam on October 16th.

But the CO2 utilisation sector is starting to look much more exciting than was previously thought.

Now, Mr Bolscher believes that carbon dioxide utilisation (CCU) will have great potential in some areas.

Although he still advises against over-optimism, believing that it is not likely to be able to store such big quantities of CO2 as with underground storage.

"CCU is not the solution for climate change, but it can be a solution for the chemical industry," he said. "You have to be a little bit hopeful if you want a new technology, [and] you also have to be realistic."

"It is very expensive, but then everything will be more expensive in an era where we can't freely burn fossil fuels," he said.

Mr Bolscher is a driving force in the "SCOT" (Smart CO2 Transformation) project, which has EU funding to explore carbon dioxide utilisation (CDU),

There are three sectors where CO2 could be used, in chemical processes, making fuels, and in mineralisation.

For chemical processes, there is already a company manufacturing a mattress made of foam which is 30 per cent from waste CO2, he said.

CO2 can be used to make a vast range of products like methane, methanol, ethylene and urea, which are already manufactured on an industrial scale and used for many different purposes.

"CCU is not the solution for climate change, but it can be a solution for the chemical industry" - Dutch energy consultant Hans Bolscher

When it comes to making fuels from CO2 Mr Bolscher was more hesitant, saying that it is technically very well possible but relatively expensive.

There is also a challenge that burning carbon based fuels in a car will release CO2 even if they are made using solar power, which may be unacceptable by as early as 2050.

This could be arguably mitigated if the CO2 used to make fuels is sourced from biomass combustion with carbon capture, or even direct air capture.

It is often seen as a solution for balancing growing amounts of intermittent wind and solar, or as a last resort solution for aviation fuel, he said.

The fact that liquid fuels can be transported and stored easily in existing infrastructure is a big advantage.

Making fuels from renewables could make sense in specific cases, for example an island community which has wind turbines but has to rely on imported liquid fuel. It will be able to use excess wind power to make methanol for vehicles and urea for use as fertiliser, Mr Bolscher said.

There is a project in Denmark to make methanol using combustion of biofuels, capture of CO2, and using it to make methanol. "It's technically possible but all together very expensive," he said.

The subject is highly controversial. "There's people constantly pushing this, particularly in Germany. And people dead against it," he said.

A third way of using CO2 is mineralisation where solid building materials can be made from waste and CO2. The CO2 there is captured permanently. "there are already two factories in the world set up for this, not very profitable yet, but definitely an interesting route we'll hear more about" he said.

www.scotproject.org

Making CO from CO2

Dutch researchers are working out how to make CO from CO2. It might not sound exciting but please read on...

The Dutch Institute for Fundamental Energy Research ('DIFFER') is doing research into how to make CO from CO2.

The reason is that carbon monoxide can be turned into liquid fuel, using a well understood industrial process (Fischer-Tropsch). But making carbon monoxide from carbon dioxide is much harder. Once it is possible to make CO from CO2, we can make liquid fuels from CO2.

The plasma-based approach being utilized is based on research that was pioneered in the nuclear submarine sector, explained Michael Gleeson, a researcher at DIFFER.

A limiting factor for how long a nuclear submarine can stay submersed is the CO2 created by its crew breathing. If there is too much CO2 in the submarine's atmosphere, it needs to come to the surface. Reusing CO2 allows for longer submersion time, as well as reducing the risk of detection associated with CO2 waste ejection.

DIFFER's approach, which builds on the original submarine research, is to power the CO2 molecules with energy from microwaves, forming a plasma or 'quasi-neutral ionised gas' that promotes molecular dissociation.

The challenge is doing it efficiently. The more energy you zap into the gas, the more excited the molecules are. You can have a high conversion efficiency and low energy utilisation, or a low conversion efficiency and high energy utilisation.

Michael Gleeson, a researcher at the Dutch Institute of Fundamental Energy Research ('DIFFER') is doing research into how to make CO from CO2

DIFFER is currently trying to find ways to achieve higher disassociation with less energy, including in conjunction with the use of catalysts.

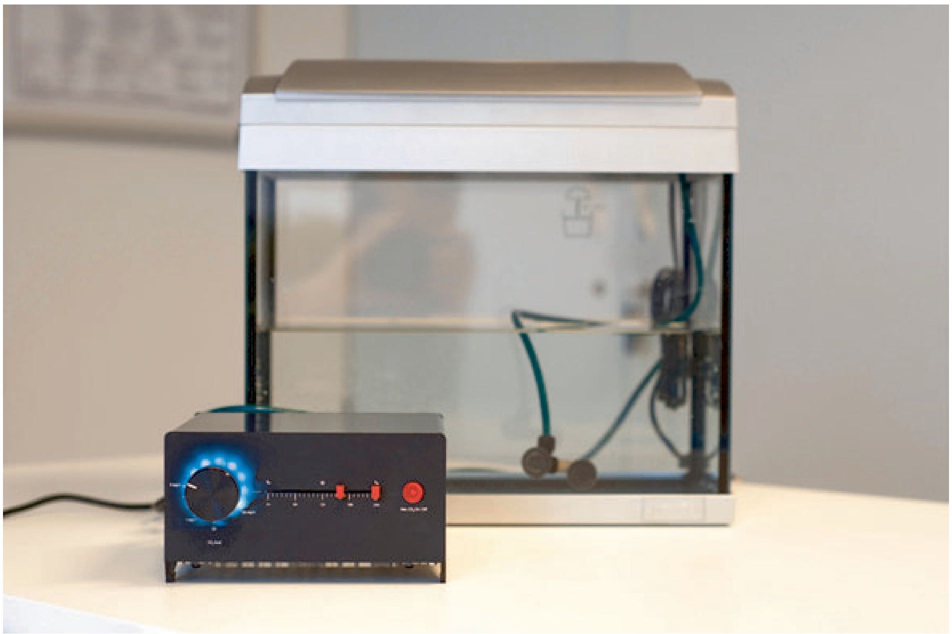
The technology could lead in other directions. It may be possible to use plasma activation to convert a methane and CO2 mixture, such as biogas, into methanol in one go.

The technology could also be used in 'calcium looping', a carbon capture process under development, where calcium oxide reacts with CO2 in the flue gas to form calcium carbonate, which is then separated to form calcium oxide and CO2 later. This separation could be enhanced with plasma, Mr Gleeson said.

Skytree - capturing CO2 from ambient air and converting to useful products

Skytree's vision is to create a carbon neutral economy by capturing CO2 from the air and re-using it to produce commercially viable products such as biofuels. The scaleable technology was originally developed by the European Space Agency.

In 1996 a project was started at the European Space Research and Technology Centre (ESTEC) in Noordwijk in the Netherlands. The aim of this project was to develop a more efficient technology for a spacecraft air-recycling system where it would extract CO2 exhaled by astronauts on-board to enable longer space missions.



Skytree's CO2 supply system for the aquarium market will be the first commercially viable product capable of capturing CO2 directly from the ambient air

They succeeded in doing so and it involves the use of tiny porous beads, which are about 3 mm in diameter but offer a contact surface area of 60/80 square meters per cubic centimeter. Also they are covered with a special substance (ie. amine groups) that can capture the CO2 as the air flows through the beads. Once the beads are saturated, the CO2 that was harvested can be released again using low grade heat. In space this cycle takes around 1.5 hours and uses the solar energy produced by solar panels on the spacecraft. The entire ESA project took over 15 years with a budget of over €70 million euros. The technology that was developed will be implemented in 2017 on the International Space Station.

The original founders of Sktyree worked on this project at ESA and wondered if this technology could work also work on planet Earth as well as being beneficial. In 2010 they enrolled in a program at the ESA Business Incubation Centre (ESA-BIC) and over a period of two years the team succeeded to adapt this technology to terrestrial conditions and they were able to patent this process. Besides the company has developed a prototype to be used in aquaria, which is also their entry market.

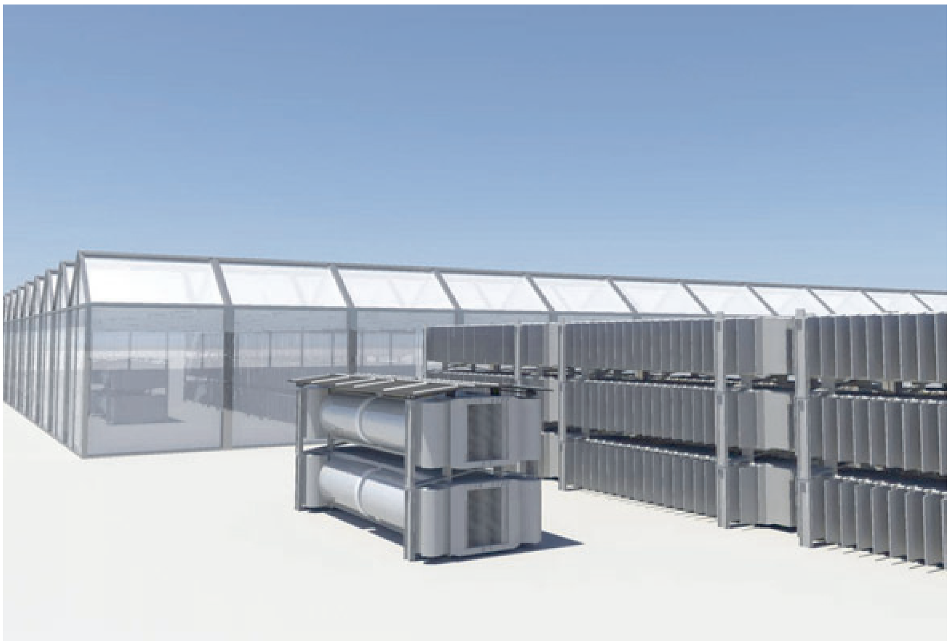
Aquarium keeping is the second biggest hobby on this planet. Through photosynthesis, CO2 makes aquatic plants greener & stronger while stabilising the PH level of the water and even reducing algae problems. In Europe alone more than 15 million people own an aquarium. Around 90% of these are fresh-water aquaria, all of which can benefit from CO2. Currently Skytree is closely working with Germany based Eheim, a world leading manufacturer of aquariums and related equipment, on developing a revolutionary CO2 supply system for the aquarium market. Once this product reaches the store shelves this would make Skytree the first company in the world to have a commercially viable product capable of capturing CO2 directly from the ambient air!

In the last decade or so Direct Air Capture has grown into a new clean tech field and worldwide only a few other companies have been able to develop technologies that can do so. Carbon Engineering (Canada), Global Thermostat (U.S.A.) and ClimeWorks (Switzerland) are among the most prominent besides Skytree (Netherlands). Interesting fact is that these industry colleagues have all been selected as finalists on the Virgin Earth Challenge. Initiated by people like Richard Branson and Al Gore this is one of the biggest science and innovation prizes in history, which is basically offered as a reward.

The potential benefits to the world are clear by now. A process capable of taking greenhouse gases out of the air, and keeping them out, on a meaningful scale would be a valuable tool in the battle against climate change. Canadian based Carbon Engineering even has Bill Gates on-board as an investor and together they are building huge sequestration devices to extract CO2 in large volumes from our planet's atmosphere. Global Thermostat from New York even estimates the total annual market for profitable use of CO2 to surpass $1 trillion annually.

Skytree works with an applied science approach and its core competency is the transfer of technology into products and applications on the small to medium scale. The aim is to bring these to market via licensing agreements with respective parties in each industry. Right now the company is able to create systems that can deliver up to 20 kilograms of pure CO2 per day. This allows their clients to become completely independent of current CO_2 solutions available on the market today. Thereby making traditional cylinders and tanks a thing of the past. With this technology the desired CO_2 is captured directly from the air and it can be released again in an extremely concentrated and pure form. Over a thousand times more concentrated even, which makes it a very valuable and useful commodity in multiple industries.

So far the company has validated more than fifty different markets where their specific technology could be implemented and is currently working on various new prototypes for clients in different markets. Besides the before mentioned aquarium market, the company is also looking at CO_2 solutions for water treatment, air purification and urban greenhouses.



A large-scale greenhouse setup of the technology

Since their technology is scalable the company aims to enter large scale markets in the long-term. The vision of Skytree is 'to create a carbon neutral economy for our planet' and the holy grail both commercially and especially environmentally would be the re-use of the captured CO_2 for the production of biofuel. This would truly represent a carbon neutral solution because gasoline would become obsolete in this way and the current waste stream could actually prove to be an unlimited source of energy for our planet.

Direct air capture proves promising for biofuel production since the CO_2 can be produced on-site in a sustainable way. Some DAC processes only require low grade heat for regeneration (below 100 degrees Celsius), which is often available at industrial processes in the form of waste heat or can be supplied by renewable energy sources. (Goeppert et al., 2014) By making further use of this waste heat the overall plant efficiency can be increased.

In essence, CO_2 is half of the reagents needed to synthesise hydrocarbons. The other half is of course H_2O and together they can be converted by having energy as an input to hydrocarbons. (Lackner et al., 2011). Proof that this notion is taken very seriously is the fact that Swiss based ClimeWorks is already working closely for several years with Audi on research into biofuel made with CO_2 that is captured from the air.

The German automaker publicly states that for the fuel that is needed for cars like their A3 Sportback g-tron the hydrogen is extracted from water via electrolysis using eco-electricity. The second needed component would be CO_2, which currently comes from biogas facilities. To make 1 kilogram of their e-gas they need 2.7 kilograms and with this technology Audi could generate the CO_2 itself in the future.

Ultimately the main advantage of capturing CO_2 from the air is that it can be decoupled from fossil fuel based power plants. CO_2 is available everywhere, and with technologies like Skytree's, it can also be made available everywhere. Since only low grade heat is needed for the regeneration process, it can be either supplied by renewable energy sources or in the form of waste heat from another industrial process. Industrial processes that are best carried out at remote locations requiring CO_2 can now directly generate it themselves, with the possibility to make use of waste heat which otherwise would have not been used.

More information

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Capture and utilisation news

GE CO2 capture to be tested at Mongstad

www.gereports.com

GE has been awarded a DOE project to pilot its CO2 capture technology for power plants at TCM Mongstad.

GE chemists have developed a solution that effectively uses a class of amino silicone compounds at various temperatures to capture and release carbon. These compounds are the same as those found in hair conditioners and fabric softeners.

A team of researchers at GE's Oil & Gas Technology Center in Oklahoma City have been awarded close to $1 million in Phase I funding by the U.S. Department of Energy's National Energy Technology Laboratories (NETL) to plan and propose a large scale pilot testing of the technology.

At temperatures of around 105 degrees F, the amino silicone materials attach to CO2 gas. When the heat is increased another 100 degrees F, these materials release the carbon and can then be re-used to capture more. One of the big advantages of GE's technology is that it does not require any water, which substantially reduces the energy required to capture the carbon.

"For decades, scientists from around the world have focused their efforts on finding more effective, less expensive ways to reduce CO2 emissions in the atmosphere," said Phil DiPietro, Technical Manager, CO2 Capture and Separation, GE's Oil and Gas Technology Center in Oklahoma City. "GE scientists have developed an innovative solution to realize both goals, which works well in the lab."

As part of Phase 1 funding, GE will advance planning of their Amino-silicone CO2 capture technology towards large scale pilot testing. It is expected that two of the six phase 1 projects will be selected for Phase 2. The Phase 2 awards for construction and execution of pilot testing are anticipated by mid-2016.

The large scale testing will aim to demonstrate the technology at industrial scale and provide final confidence in the maturity of the Carbon Capture technology for full scale commercial deployment, reducing emissions from power plants and other large industrial point sources of CO2.

Robert Perry at GE is using compounds normally found in bathrooms and laundry rooms like shampoo, conditioners and textile softeners to trap carbon dioxide

Air Liquide launches cryogenic CO2 capture system

www.airliquide.com

Air Liquide has inaugurated Cryocap™, a unique industrial installation that enables the capture of CO2 released during hydrogen production via a cryogenic process.

Connected to Air Liquide's largest hydrogen production unit in France, located in Port-Jérôme, Notre-Dame-de-Gravenchon, Normandy, Cryocap™ represents an investment of around 30 million euros supplemented by an additional public financial support of close to 9 million euros.

Developed jointly by Air Liquide R&D and Engineering & Construction teams, Cryocap™ is being rolled out for the first time in Port-Jérôme, on the SMR (Steam Methane Reformer) of Air Liquide which produces hydrogen for the neighboring refinery, Esso Raffinage SAF (ExxonMobil group). Hydrogen is used to remove the sulfur content of the automotive fuels the refinery produces.

Cryocap™ is the first CO2 capture technology using a cryogenic process and enables the capture of CO2 emissions resulting from the production of hydrogen by natural gas reforming, while improving efficiency, leading to an increased hydrogen production. After being purified, the captured CO2 can be used to meet a variety of industrial needs for carbonic gas supply. The Cryocap™ unit has an annual capture capacity of 100 000 tonnes of CO2 at this site.

Study on mobile carbon capture in Poland

www.ichpw.pl/en

A mobile carbon capture technology that can remove up to 1000 kg CO2/day from a coal power plant is described in a paper from the European Commission.

The describes the trial of a carbon capture plant that removes CO2 via chemical absorption in a coal-fired power plant in Poland. The pilot plant was designed, erected and operated by the Polish Institute for Chemical Processing of Coal in collaboration with an industrial partner, TAURON. The plant absorbs CO2 using a chemical (amine-based) solvent.

The authors say this technology is the most effective for coal-fired power plants and can be implemented with existing units. The plant is mobile, so it can be tested in various locations, and flexibly designed, which means it can be used to test changes to process. This allowed the researchers to investigate the influence of different process parameters on CO2 recovery and energy demand (the two most important indicators of process efficiency).

In 2013, the plant was transported and connected to TAURON's Laziska Power Plant in Poland, where 550 hours of tests were conducted using the solvent monoethanolamine (MEA), a baseline solvent suitable for extended comparisons. During testing, over 90% of CO2 was removed from the flue gases and in excess of 19 000 kilograms of CO2 was captured (approximately 1000 kg per day).

Process variations revealed that CO2 recovery is dependent on a number of factors, including solvent concentration, CO2 partial pressure and temperature.

The amount of CO2 removed from the flue gas fluctuated by up to 20% depending on these factors, which indicates that operating the process under optimal conditions could generate significant energy savings.

The researchers were particularly interested in process energy demand, as it is the major limiting factor to the widespread implementation of solvent-based CCS. Energy use in the vast majority of tests was below 4 megajoules per kilogram.

The mobile carbon capture pilot plant during tests at the Łaziska Power Plant in Łaziska Go´rne, Poland

Transport and storage news

UK CO2 storage site capacity confirmed

www.bgs.ac.uk

The Goldeneye reservoir in the North Sea has been independently verified as suitable for the safe storage of carbon dioxide from an Aberdeenshire power station.

A team of experts from the British Geological Survey (BGS) and Heriot-Watt University recently completed an independent external review of the storage plan for the proposed Peterhead Carbon Capture and Storage project, one of the two preferred bidders in the UK Government's Carbon Capture and Storage Commercialisation Programme.

The project, which is led by Shell with strategic support from SSE, proposes to capture carbon dioxide (CO2) from an existing gas-fired power-station at Peterhead in Aberdeenshire and to store this 100 km (62 miles) offshore in geological strata at a depth of around 2600 metres beneath the outer Moray Firth.

The plan is to store ten to fifteen million tonnes of CO2 over a ten- to fifteen-year period commencing around 2020, but the site is being qualified for twenty million tonnes of storage to allow for potential extension of the injection period. Storage will utilise the depleted Goldeneye gas condensate field with the Captain Sandstone reservoir as the primary storage container.

The review took place over a period of several months in the first part of 2014, and followed an iterative process of document review, response and discussion between the review team and geoscientists and engineers from Shell.

Dr Andy Chadwick, BGS, who led the review, said: "It is clear that the technical studies carried out by Shell are founded on a comprehensive suite of modern high-quality datasets and are very robust. We conclude therefore that the Goldeneye storage site is characterised and understood to a high level of detail and is suitable for the purpose of storing up to 20 million tonnes of CO2 injected according to the specified plan, with the likelihood of significant additional capacity. The British Geological Survey has prepared a signed statement to this effect."

The British Geological Survey has independently confirmed that Shell's Goldeneye field is suitable for storing up to 20 million tonnes of CO2 (Image ©Shell)

NETL Atlas shows increase in CO2 storage potential

netl.doe.gov

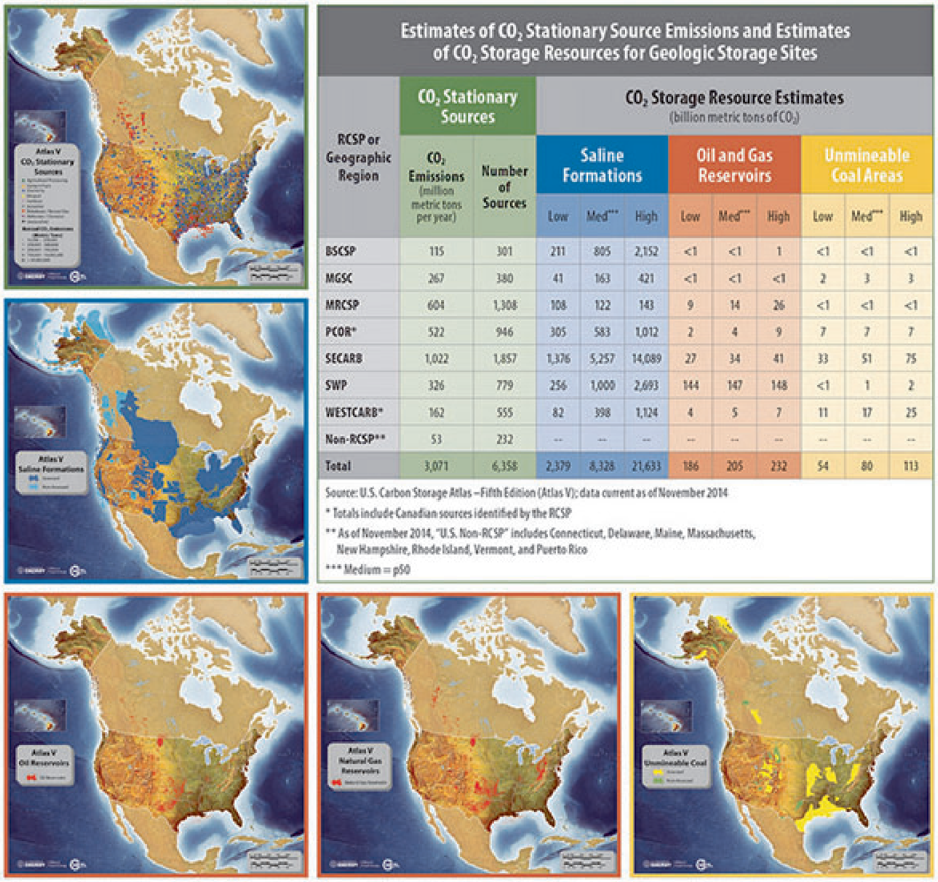
The National Energy Technology Laboratory (NETL) has released the fifth edition of the Carbon Storage Atlas (Atlas V).

The refined CO2 storage estimate of 2,600 billion metric tons reported in Atlas V represents an increase over the 2,380 billion metric tons reported in the previous edition, The United States 2012 Carbon Utilization and Storage Atlas (Atlas IV). The increase is a result of improved accuracy and precision in storage resource calculations, additional information from formation studies, and refinement of storage efficiency.

Atlas V is a coordinated update of carbon storage resources, activities, and large-scale field projects in the United States. It highlights potential CO2 storage resources in saline formations, oil and natural gas reservoirs, and unmineable coal seams. The new edition also presents a detailed look at the Regional Carbon Sequestration Partnership Initiative's large-scale field projects.

For each large-scale field project, Atlas V provides a summary of approaches taken, technologies validated, and lessons learned in carrying out key aspects of a CCS project: site characterization; risk assessment; simulation and modeling; monitoring, verification, accounting, and assessment; site operations; and public outreach.

These efforts collectively contribute to the development of regional carbon management plans. They also aid in regulatory development, as well as help determine appropriate infrastructure for CCS commercialization in each region.



Estimates of CO_2 Stationary Source Emissions and Estimates of CO_2 Storage Resources for Geologic Storage Sites

RCSP or Geographic Region	CO_2 Stationary Sources		CO_2 Storage Resource Estimates (billion metric tons of CO_2)								
	CO_2 Emissions (million metric tons per year)	Number of Sources	Saline Formations			Oil and Gas Reservoirs			Unmineable Coal Areas		
			Low	Med***	High	Low	Med***	High	Low	Med***	High
BSCSP	115	301	211	805	2,152	<1	<1	1	<1	<1	<1
MGSC	267	380	41	163	421	<1	<1	<1	2	3	3
MRCSP	604	1,308	108	122	143	9	14	26	<1	<1	<1
PCOR*	522	946	305	583	1,012	2	4	9	7	7	7
SECARB	1,022	1,857	1,376	5,257	14,089	27	34	41	33	51	75
SWP	326	779	256	1,000	2,693	144	147	148	<1	1	2
WESTCARB*	162	555	82	398	1,124	4	5	7	11	17	25
Non-RCSP**	53	232	--	--	--	--	--	--	--	--	--
Total	3,071	6,358	2,379	8,328	21,633	186	205	232	54	80	113

Source: U.S. Carbon Storage Atlas – Fifth Edition (Atlas V); data current as of November 2014

* Totals include Canadian sources identified by the RCSP

** As of November 2014, "U.S. Non-RCSP" includes Connecticut, Delaware, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, and Puerto Rico

*** Medium = p50

Atlas V Estimates of CO2 Stationary Source Emissions and Estimates of CO2 Storage Resources for Geologic Storage Sites

Secretary Moniz announces new CO2 storage network

energy.gov

U.S. Energy Secretary Ernest Moniz has announced the formation of an international initiative to facilitate collaborative testing of advanced CCS technologies at real-world, saline storage sites.

The Carbon Sequestration Leadership Forum's (CSLF) Large-Scale Saline Storage Project Network will form a global network of large-scale carbon dioxide (CO2) injection sites that can share best practices, operational experience, and key lessons to advance the deployment of CCS.

The CSLF is a Minister-level international climate change initiative focused on developing and deploying CCS technologies globally. There are currently more than 20 large CCS projects in operation or under construction around the world.

Secretary Moniz's announcement followed a meeting of energy ministers at the 6th CSLF Ministerial Meeting in Riyadh, Saudi Arabia. The U.S. and Saudi Arabia co-chaired this year's meeting.

Secretary Moniz noted that the new collaboration builds on the success of the CO2 Capture Test Center Network, chaired by Norway since 2013. The U.S. will take the lead on the capture center initiative next year.

Secretary Moniz's announcement capped a productive meeting of the CSLF, during which Romania and Serbia were welcomed as the newest members of the multinational organization.

Prospects for CO2-EOR in the UK Continental Shelf

An Energy Research Partnership report concludes there is a narrow window of opportunity to deploy CO2-EOR in the UK North Sea.

The maturity of most North Sea oil fields means there is a narrow time window to deliver CO2-EOR, with potential incremental oil recovered declining by three quarters, from about 500 million barrels, between 2025 and 2030, if a sufficient and reliable supply of CO2 is not delivered early enough. Redevelopment costs are likely to restrict the reopening of closed fields.

Decisions made in the next two years will determine the extent that the benefits from CO2-EOR are realised, including taxable oil revenues, offering low-cost storage for CCS and sustaining the wider oil industry. Several CCS capture plants will need to be operational by 2025 to deliver the supply of CO2. Early approval of both CCS Competition projects will enhance the success, followed by Phase 2 plants in operation by early 2020s.

Developing CO2-EOR could extend the life of the oil fields for up to 15 years, delivering a range of benefits including additional taxable oil revenues, delaying of decommissioning and sustaining the wider UK oil industry. By providing secure, low-cost CO2 storage, CO2-EOR will benefit the development of CCS, which, in turn, will reduce the cost of achieving the UK's energy and carbon targets.

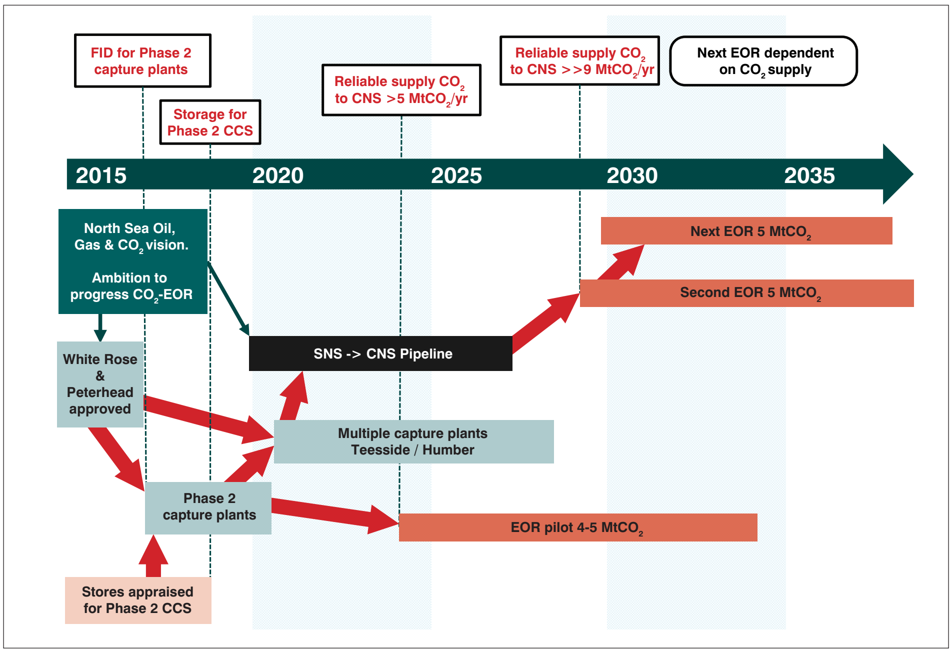
Furthermore, developing the CO2 transport infrastructure in the North Sea to supply CO2-EOR could help open up the best and largest CO2 storage assets in Europe. A new industry could be developed in the UK North Sea storing CO2 and providing opportunities to manage emissions from neighbouring EU member states.

With multiple parties involved, a new commercial framework will be needed to de-risk the interactions across the supply chain, between the emitters, oil field operators, pipeline companies and the back-up stores, which will be needed to manage the CO2 flows for EOR projects.

Oil price variability presents a significant risk to CO2-EOR investments. Interventions to the offshore tax regime will be needed to desensitize projects. Early engagement with the public will also be needed to inform developments and establish acceptance for CO2-EOR.

Recommendations

- The oil and CCS sectors need to be coordinated, within Government and across industry.
- Early policy decisions on CCS Phase 1 & 2 will determine the outcomes of CO2-EOR and will be improved if both Peterhead and White Rose go ahead.
- The offshore tax regime needs to support CO2-EOR's high expense and risks.
- Enable a CO2 transport/infrastructure company to reduce risks for emitters, stores and CO2-EOR.



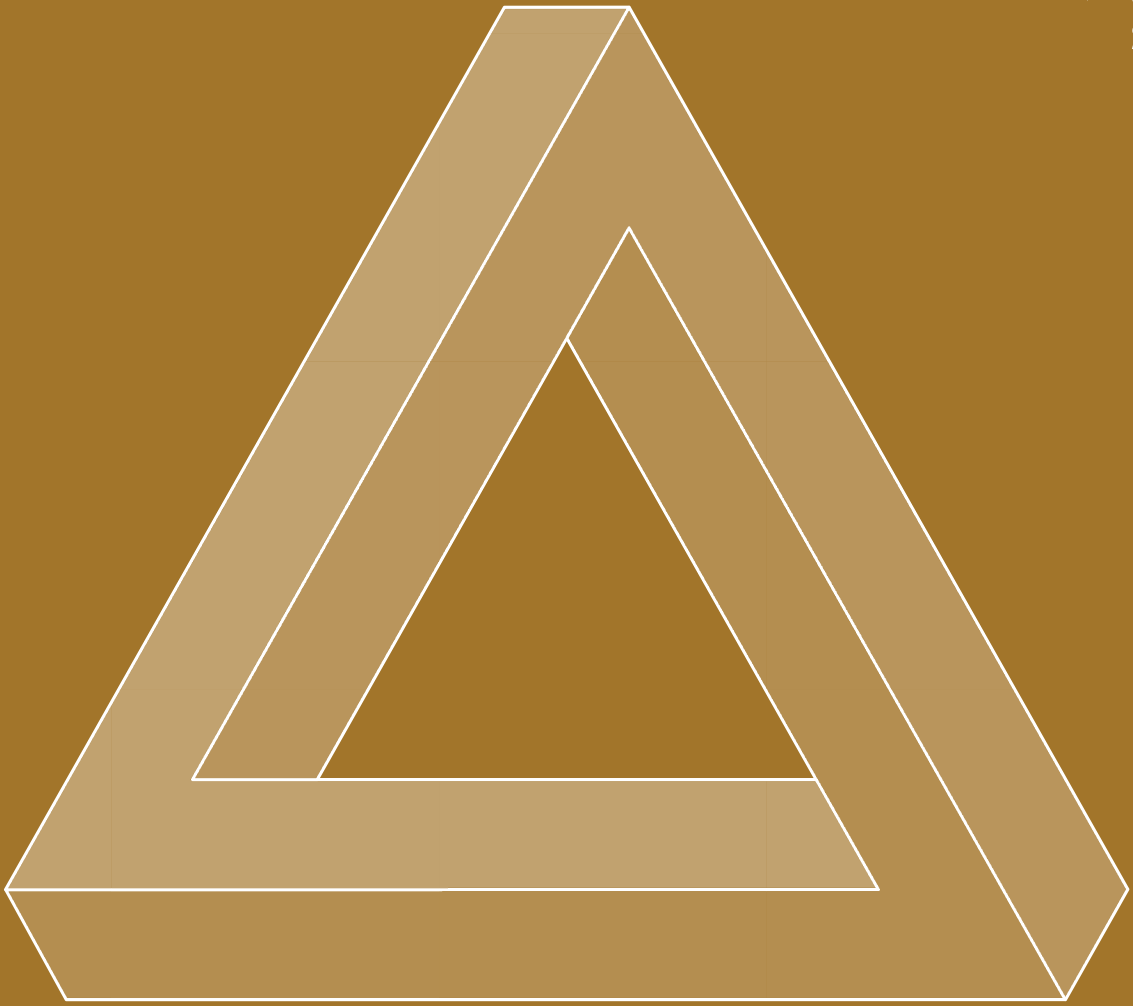
Critical milestones and timeline for the delivery of early CO2-EOR projects, showing critical dependencies (red arrows). Coordination of these complex interdependencies requires a clear ambition to maximise benefits

More information

The Energy Research Partnership is a high-level forum bringing together key stakeholders and funders of energy research, development, demonstration and deployment in Government, industry and academia, plus other interested bodies, to identify and work together towards shared goals.The report can be downloaded here:

www.erpuk.org

CCEMC
Climate Change & Emissions Management Corporation



TRANSFORMING CARBON INTO A VALUED RESOURCE IS YOUR GOAL. TURNING IDEAS INTO ACTION IS YOUR GRAND CHALLENGE.

CCEMC GRAND CHALLENGE: INNOVATIVE CARBON USES ROUND 2

The inaugural round of the Climate Change and Emissions Management Corporation (CCEMC) Grand Challenge was a vital step in reducing GHG emissions. 24 winners were chosen from 344 submissions from 37 countries on six continents; the winners each received $500,000 to develop technologies that create new carbon-based, value added products and markets.

The second round of the CCEMC Grand Challenge is open for submissions until January 18, 2016. This round is focused on near deployable ideas that turn carbon waste into a valued resource. Winners will receive $3 million in funding to commercialize their technology in Alberta.

Is your idea up to the challenge? **Apply now at ccemcgrandchallenge.com**