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Front cover: Schlumberger Wireline performing logging operations at the Midwest Geological Sequestration Consortium's Illinois Basin – Decatur Project CCS1 site

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Midwest Illinois Basin – Decatur Project

The Midwest Geological Sequestration Consortium's (MGSC) Illinois Basin – Decatur Project (IBDP) is a collaboration of the MGSC, the Archer Daniels Midland Company (ADM), Schlumberger Carbon Services, and other subcontractors to inject 1 million metric tons of carbon dioxide.

By Dr. Sallie E. Greenberg, Assistant Director of the Advanced Energy Technology Initiative

The project will inject CO2 at a depth of 7,000 ft at a site owned by ADM in Decatur, Illinois. ADM provides the carbon dioxide as a byproduct of its production of fuel ethanol from Illinois corn.

MGSC is one of seven regional projects funded by the US Department of Energy to test the safety and effectiveness of carbon capture and storage as a measure to reduce emission of carbon dioxide, a greenhouse gas, into the atmosphere.

Injection and monitoring

The IBDP began operational injection on November 17, 2011. In early June 2013, a major milestone was reached as the injected volume reached the 500,000 metric ton mark. Injection will continue through late 2014 at which time the injection operation will shut down when 1 million metric tons have been injected. Environmental monitoring will continue for at least three more years, but likely longer.

To date, the injection has proceeded as planned with the receiving reservoir, the Mount Simon Sandstone, readily taking the injected volume of 1,000 metric tons per day. Capacity, injectivity, and containment have all met pre-injection expectations and researchers continue to focus on validating the project's environmental framework, understanding the carbon dioxide distribution in the subsurface, and improvements in operations and monitoring well equipment.

Pressure readings from an observation well 1,000 feet from the injection well suggest that the injected CO2 has not reached the middle of the 1,500-foot-thick Mt. Simon reservoir. Models that project the movement of the CO2 plume over 100 years suggest that the CO2 will remain below this level. Data from a 3D vertical seismic profile acquired in early April 2013 are expected to further define the position of the plume.

From left: Tom Stone (ADM), Rob Finley (ISGS), Sallie Greenberg (ISGS), and Scott Marsteller (Schlumberger Carbon Services) at the IBDP injection well head on startup day, November 17, 2011. (Photo: Daniel Byers for the MGSC)

Further development

The IBDP research effort, part of the U.S. Department of Energy – National Technology Laboratory's Regional Carbon Sequestration Partnership program, is now complimented by the development of additional injection capacity of 2,000 metric tons per day, under development as part of the Illinois Industrial Carbon Capture and Storage project. Both sites are at the facilities of the Archer Daniels Midland Company in Decatur.

The combined projects will allow evaluation of subsurface injected carbon dioxide from two high-volume injection wells that together will advance understanding of the volumes to be dealt with at a scale much more resembling storage from a commercial pulverized coal power plant.

The Illinois Basin – Decatur Project has attracted international attention as one of the few onshore projects in the world to successfully reach the demonstration stage, and numerous international guests have visited the site. Countries represented include Norway, China, Taiwan, South Korea, Spain, Japan, Brazil, and others. Worldwide interest in the project continues and lessons learned to date will be detailed in an invited seminar for European researchers to be held in Oslo, Norway in October 2013.

More information

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Battelle leads CO2 storage with EOR project in Michigan

As part of a national effort to develop methods for carbon storage, Battelle is beginning a large-scale carbon dioxide injection through the Midwest Regional Carbon Sequestration Partnership (MRCSP) program in the oil fields of Michigan's Northern Reef Trend.

The MRCSP is a multi-year research program led by Battelle with a mission to identify, test and further develop the most effective approaches to carbon dioxide (CO2) utilization and storage in nine states within the Midwest and Northeast.

"This project will explore what CO2 is doing in the deep underground, its migration and reactions," said Neeraj Gupta, senior research leader in Battelle's Energy & Environment business unit. "We're not only looking at storage, but we're also figuring out how to utilize CO2 before it's stored."

Established 10 years ago by the U.S. Department of Energy's National Energy Technology Laboratory (NETL), the MRCSP is one of seven Regional Carbon Sequestration Partnerships in the U.S. This project will build on the work completed by MRCSP's industry and research members during earlier phases of the program, which included smaller-scale testing and mapping of geologic formation across the region.

The current project in Michigan is designed to inject and monitor at least 1 million metric tons of CO2 into a series of oil fields in different stages of their production life-cycles. The first test in the series will inject up to 500,000 metric tons of CO2 into a depressurized, late-stage oil field that has undergone primary production and enhanced oil recovery for several years and is now near the end of its productive life.

The MRCSP team instrumented the wells and pipelines to obtain geological and operational data that will be used to evaluate monitoring technologies, validate reservoir simulation models, and provide material balances on the enhanced oil recovery (EOR) operations to determine how much CO2 is retained in the formations.

The MRCSP team will use special techniques to track the CO2 and quantify the amount that is retained in the formation after the oil is removed, both during and after the active injection phase (Figure 3). The CO2 will be injected into the Niagaran pinnacle reef trend, an oil field comprising highly compartmentalized ancient coral reefs buried about 6,000 feet below the ground surface.

As shown in Figure 3, multiple monitoring technologies are being deployed to assess the fate of the CO2, including pressure monitoring, wireline logging (e.g. pulsed neutron capture), vertical seismic profiling,

Figure 1 - photograph of the CO2 injection well at the project site

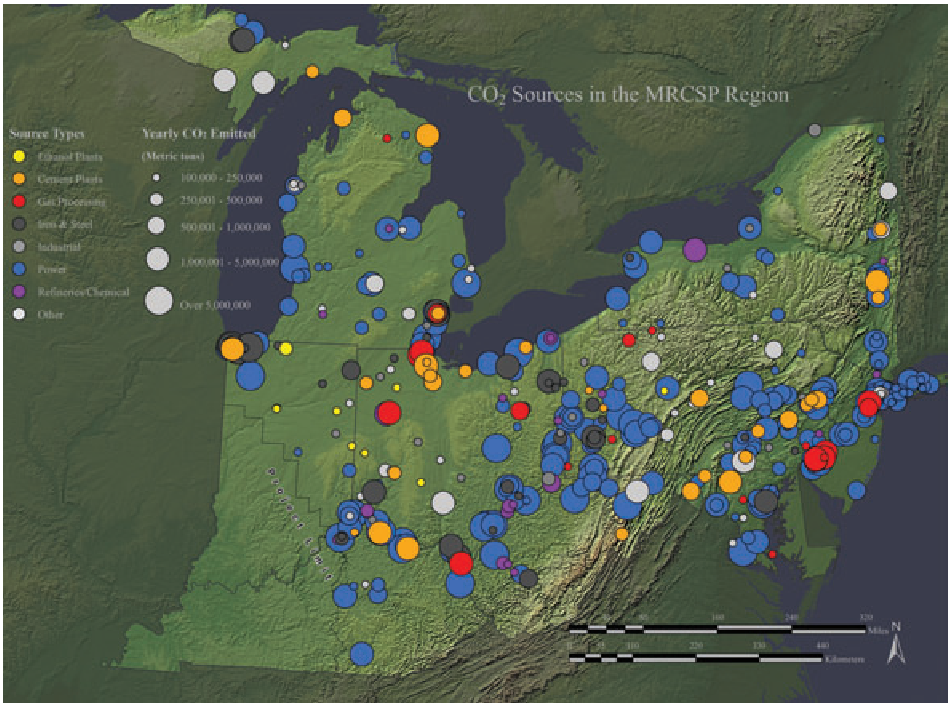

Figure 2 - a review of industrial CO2 sources in the MRCSP Region belies the importance of CCS

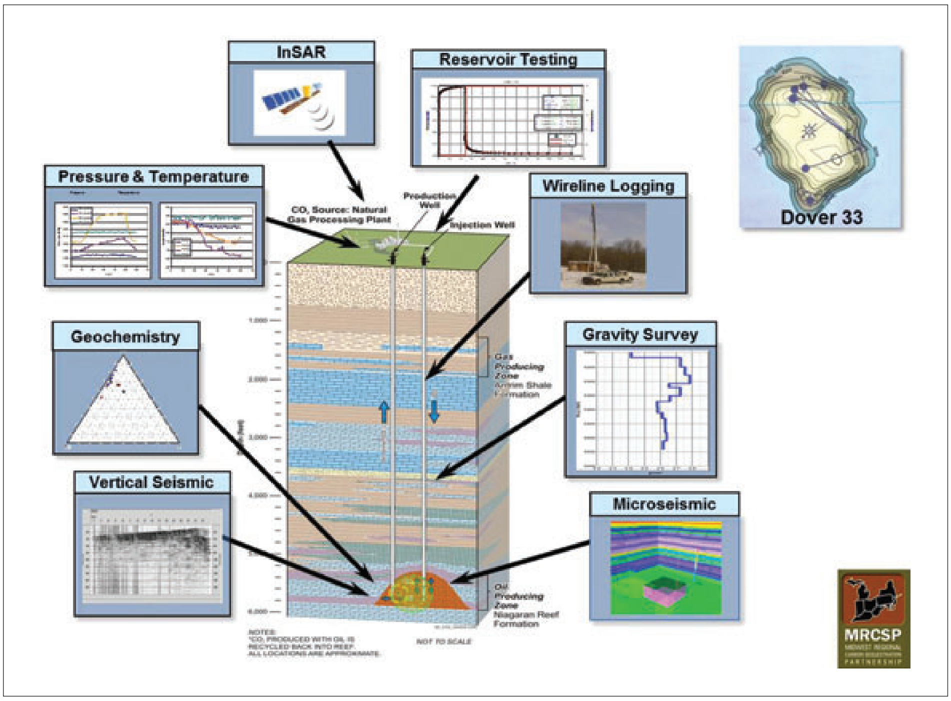

Figure 3 - monitoring options under testing at Dover 33 Field

microseismic monitoring, microgravity monitoring, and surface deformation monitoring using satellites. Results of the research are being used to improve understanding of CO2 migration and oil production in reservoirs, interaction with surrounding media, geochemical and geomechanical impacts, and storage capacity.

"The EPA is drafting CO2 regulations based on President Barack Obama's renewed emphasis on climate change, which leads Battelle into a new business area," said Gupta. "There is a lot of potential for this type of technology in the Midwest. We're testing, proving and scaling it up to commercial sizes."

Gupta said that carbon capture, utilization and storage represent means for a secure energy future, and the knowledge gained from this research will be valuable to the regional economy.

"The idea of storage and injection is not new, but this specific type of application is unique," said Gupta. "It's just a matter of developing it further and ensuring its safety."

During the last year, Battelle's MRCSP team has worked with Core Energy, LLC, the owner and operator of the oil fields, to conduct baseline geologic characterization and advanced monitoring and to prepare the wells for the injection phase. These fields already are permitted for injection as part of the routine EOR operations. In this first leg of the field test, MRCSP expects injection rates of approximately 1,000 metric tons of CO2 per day.

One way to combat global climate change is to limit greenhouse gas (such as CO2) emissions from large-scale emitters such as coal burning power plants. Carbon capture, utilization and storage seeks to capture CO2 as it goes up smokestacks, pressurize and dry it, then inject it deep beneath the ground (in this case, 6,000 feet), in formations known to hold hydrocarbons for millions of years. Carbon capture, utilization and storage is an important class of technologies and represent means for a secure energy future. The knowledge gained from this research will be of broad value to the regional economy and its industrial base.

The project is largely funded by DOE-NETL under the MRCSP program, with contributions by industry and research team members. A complete list of team members can be found on the MRCSP website.

More information

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At major technology centers and national laboratories around the world, Battelle conducts research and development, designs and manufactures products, and delivers critical services for government and commercial customers. Headquartered in Columbus, Ohio since its founding in 1929, Battelle serves the national security, health and life sciences, and energy and environmental industries. For more information, visit:
www.battelle.org

Midwest Regional Carbon Sequestration Partnership (MRCSP): www.mrcsp.org

Core Energy, LLC is actively involved in innovative oil and gas exploration and production technologies throughout Michigan. Core was the first company in Michigan to utilize carbon dioxide on a commercial scale to produce oil that would otherwise be stranded from existing oil fields. The company is also using modern techniques to explore for new reserves located near existing oil fields. Core Energy is headquartered in Traverse City, MI. More information about the company is available at:
www.coreenergyholdings.com

BSCSP begins CO2 injection in Washington basalt formations

Led by Montana State University, the Big Sky Partnership (BSCSP) is testing CO2 storage in ancient basalt lava flows, a model that could be applied in many other parts of the world.

By Lindsey Tollefson, BSCSP Project Manager

In late July 2013, the Big Sky Carbon Sequestration Partnership (BSCSP) kicked off the injection phase of a field demonstration project to determine if greenhouse gases can be permanently stored in underground geologic formations.

One of the most unique aspects of the project is the type of geologic formation: layers of ancient basalt flows formed by cooling lava. "We are excited to be conducting, through our partners, the world's first injection of pure carbon dioxide into basalts," said Lee Spangler, BSCSP Director.

On behalf of BSCSP, researchers at Battelle are teaming with Boise, Inc. to conduct the test on Boise property in southwestern Washington State, near Wallula. Over a two-week period, the team injected nearly 1,000 tons of CO2 one-half mile underground into porous layers of basalt. Above and below the porous layers are impermeable rock layers that will trap the CO2 in place. In addition, laboratory experiments have shown that basalt rocks can rapidly convert injected CO2 to solid carbonate minerals, permanently trapping and securing the carbon dioxide.

"We have been conducting laboratory tests on basalts from the region for several years that have conclusively demonstrated the unique geochemical nature of basalts to quickly react with carbon dioxide and form carbonate minerals or solid rock, the safest and most permanent form for storage in the subsurface," said Battelle project manager Pete McGrail. "However convincing the laboratory data may be, proving the same processes operate deep underground can only be done by conducting a successful field demonstration."

BSCSP is leading a project to inject CO2 into lava flows

With the initial injection complete, the research team will begin a 14 month monitoring period during which time they will examine fluid samples from the injection well to look for changes in chemical composition, as well as compare actual results to predictions made with the supercomputer at the Pacific Northwest National Laboratory (operated by Battelle for the Department of Energy). At the end of the monitoring period, rock samples taken from the well are expected to exhibit the formation of carbonate mineralization, or limestone crystals, as a result of the CO2 reacting with minerals in the basalt.

If the demonstration project is successful, basalt flows in many parts of the world could serve as storage locations for CO2 emissions from a variety of industrial facilities. "Basalts have the potential to store over 300 years of the carbon dioxide emissions in the six-state Big Sky region," Spangler said. "Perhaps more important is their storage potential in countries with rapidly increasing energy use, specifically China and India."

The demonstration is approximately 80

percent funded through the U.S. Department of Energy's (DOE) National Energy Technology Laboratory. To date, $12 million has been committed to the pilot project. Other contributors include Schlumberger, Praxair, Royal Dutch Shell, Boise Inc., and Portland General Electric.

BSCSP, which is led by Montana State University, is one of seven partnerships involved in the DOE's Regional Carbon Sequestration Partnership Program. BSCSP is also managing a large scale, eight-year CO2 injection project in northern Montana, which is currently in its initial characterization and permitting phase.

More information

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The Industry and the CCS Legal Framework

Through interviews with both 'upstream' and 'downstream' CCS industry representatives, Marko Maver sets out to examine how the industry has come to perceive the legal and regulatory framework for CO2 storage in the EU and assesses any barriers that remain.

By Marko Maver, University of Sheffield, UK

Across the 'CCS network', from academic and research institutions, to the industry and policy and decision-makers, the progress made over the last decade or so, in terms of making CCS a reality, should not be underestimated. Even in getting the general public on board, progress has been made, though admittedly rather slow, or perhaps better said, too slow. Any progress has to a large extent been due to the extensive collaborative efforts within this network.

The idea for CCS was born in the R&D laboratories of the oil & gas industry in the mid-1990s, but it can be said that today, in 2013, it has finally become of 'legal' age. Becoming of legal age, however, does not presuppose any claims about maturity.

How long that will take depends on a number of factors, including public acceptance of the technology, secured financing for demonstration projects, as well as the industry's acceptance of the legal and regulatory framework. In terms of the latter, it is particularly important for the industry to view these frameworks as sufficiently loose enough to allow them to operate without any obstructions, yet stringent enough to provide legal certainty in an unlikely case things go wrong.

By conducting a number of interviews with both 'upstream' and 'downstream' CCS industry representatives, this paper set out to examine how the industry has thus far come to perceive the legal and regulatory framework for CO2 storage in the EU and whether, or what barriers there remain in this respect.

Main issues within the legal framework for CCS in the EU

As the name suggests, the (2009/31/EC) directive on the geological storage of CO2 (hereinafter the CCS Directive) is aimed primarily at regulating the storage of the CO2, albeit some provisions concerning capture and transport as well, in order to facilitate integration of all phases of the CCS chain.

The enabling legal framework for carbon capture and storage in the EU has come to be recognized as one of the most extensive pieces of such legislation in the world, covering everything from site exploration, selection, permitting, monitoring, reporting, corrective measures in case of leakage, liabilities, financial provisions, transfer of responsibility, and third party access to the transport and storage networks.

Nevertheless, while the CCS Directive is undoubtedly a comprehensive piece of legislation, which has served as a model for other countries wishing to develop legal frameworks for CCS within their territories, the industry representatives in Europe continue to express concern over a number of concepts serving as potential legal and regulatory barriers to the further development of CCS in Europe. Of these, the most pressing issues for the industry that have been identified remain the long-term (financial) liability, and third-party access, which however, remain primarily concentrated in the 'downstream' (i.e. oil & gas) CCS industry.

For the 'upstream' industries (i.e. power generation, petrochemicals, cement), the main issues mentioned focused mainly on the capital expenditures and the lack of strong financing mechanisms. Furthermore, a number of respondents also specifically mentioned the favouritism showed by the UK competition towards post-combustion technology.

Given that the focus of the EU legal and regulatory framework in the EU is on the storage component, the majority of the chosen respondents were primarily from the 'downstream' end of the CCS chain, thus the focus here is on the above mentioned issues; long-term liability and third-party access.

Long-term financial liability

'Downstream' CO2 storage operators essentially have fairly little incentive to store the CO2, given that the majority of the reward is to be, technically at least, kept by the capture operators. This incentive is provided by the EU ETS. However, the current EUA price (4.43EUR/tonne as of August 23, 2013) is at one of its lowest points in history, thus, as one respondent pointed out, "there is no denying the fact that this will not provide sufficient incentive at all, in particular for the storage operators solely dealing with storage, not including any EOR into their revenue stream".

So, when an operator dealing with pure storage is required to set aside a part of their revenue stream, for post-closure monitoring and possible remediation efforts, with a low and volatile EUA price, there is indeed very little incentive to move forward.

Respondents also mentioned that, under the current policy and regulatory framework, it is for them still unclear as to how long-term financial liability is to be handled and managed. Pursuant to the current financial provisions (Art. 19 and Art. 20) storage site operators are required to prove their financial competence, and make a financial contribution to the competent authority (CA) for the monitoring and possible remediation purposes, following site closure, and until the transfer of responsibility to the state.

However, even then, the full extent of liabilities is not transferred, as the Directive makes specific references to situations where costs incurred by respective competent authorities (CAs) can be recovered from the operator (Art. 18(7) - i.e. willful deceit, negligence, provision of deficient data).

As Art. 20(1) of the CCS Directive states, it is up to the Member States to decide the arrangements based on which financial contribution is made available ot the CA. Whether financial liability is to be handled via a type of a 'club-fund', whereby operators pay into a common fund, or whether insurance companies will be providing specific CCS types of insurances, as one respondent mentioned, the fact that there is a lack of any specific set up in the CCS Directive, or subsequent legislation/regulation, was identified by respondents as a significant barrier. A report by the UK's DECC in its April 2012 CCS Roadmap identified this very area, the liability arrangements, to come under scrutiny in 2015 when the CCS Directive is set to be reviewed.

Last, but not least, in relations to any civil liabilities for harm to human health, and private property rights issues in case of property damage, resulting from CO2 leakage, there did not seem to be any concern amongst the respondents, and if not identified on their own, when asked, majority stated that they believed such issues were sufficiently covered under the existing UK regulations, and did not pose as a major barrier.

Third-party access

Under the CCS Directive (Art. 21), it is up to the Member States to determine the detailed modalities for access to transportation networks and CO2 storage sites (Art. 21(1)),

which needs to be provided in a transparent and non-discriminatory manner (Art. 21(2)). While the decision to provide, or deny, access to the transportation network or a storage site ultimately still resides in the hands of the operator, their decision needs to be justified. For example, if denying access, the operator can do so on the ground of a lack of capacity, or incompatibility of technical specifications which cannot be economically and ecologically overcome. Given the potential transboundary nature of storage sites and transportation networks, pursuant to Art. 22 of the CCS Directive, Member States are also obligated to implement dispute settlement arrangements, as well as are required to act jointly (Art. 24).

The second major issue identified by the respondents was the issue of third party access. Depending on the carbon price, access to transportation networks and CO2 storage operations could become a condition for competitive operation in the EU energy market, as Scott Brockett form the EU Commission points out (2009). In its writing of the CCS Directive, the Commission decided to be somewhat vague, or better said, adopted a lighter regulatory approach.

This was done on purpose given the relative early stages of CCS development, however, it said that third-party access will be kept under the scope in case of any anti-competitive practices emerging. When asked about their views on the issue, majority of respondents pointed out that while it is true that todate the issue of third party access has not come up yet, however, as a representative from BP pointed out, "once CCS takes off, this might prove to be the largest source of commercial uncertainty for the industry…the Commission will really need to address this, once the Directive comes under review in 2015".

In the UK, third-party access is addressed by the CO2 Storage (Access to Infrastructure) Regulations 2011, which were seen by the respondents for the most part as "good", "fair", and "straight forward and reasonably well understood". However a number of issues seemed to remain for the industry in relation to third-party access.

One respondent suggested that there remains the lack of any specific provisions in relation to the revenue stream: "If you build up the infrastructure and another power station wants to tap in your infrastructure, how do you decide the revenue or the tariff?". Yet another was concerned that "if something happens to your storage facility, after you take on the third party, who is responsible for that? In other words, where does the responsibility and accountability come from for the molecules coming from various pipelines and/or parties?"

Conclusion

There is no doubt that Europe has one of the best sets of regulations out there, that are, as seemed to have been a common agreement amongst the respondents, reasonably straight forward and reasonably well understood.

In terms of procedural requirements at least, the UK deployment of the CCS Directive was also considered pretty well understood. As mentioned, the main legal and regulatory issues within the industry seem to revolve around the long-term financial liability and third-party access. Nevertheless, it should be pointed out that for the most part the respondents seem to be rather positive in regards to these two issues being addressed in the future, in particular in light of the 2015 review of the CCS Directive.

More information

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North American bottom-up CCS approach delivers more than EU's top-down, says IEA

The National Energy Technology Laboratory's (NETL) Carbon Storage R&D meeting took place in Pittsburgh in the United States, reports Bellona. John Gale, general manager of the International Energy Agency (IEA) Greenhouse Gas R&D Programme, addressed the conference and said the United States' bottom-up approach to CCS project development had produced much better results than the European top-down approach. www.bellona.org

The more phased approach to developing CO2 Capture and Storage (CCS) projects over the last decade in the US seems to have boosted both R&D and public acceptance more than in Europe. Europe has instead been characterised by politicians trying to drive industry, but without taking the necessary steps. GHG News reported Gale to have said that "the Europeans took a top-down approach of setting a high-level policy goal of 20 demonstration projects by 2020, but they didn't do much of the underpinning R&D.

Whereas the U.S. took a bit of the alternative approach, which saw the phased buildup of projects and bringing people on board." Gale further noted: "You bring the learnings from smaller projects and use them in the demonstration project. That ensures that you have a scientific basis to explain to the politicians that the process is safe and secure, that you're not taking a risk with investments."

One such key development in Canada, where CCS project conditions are more similar to those in the US than EU, is SaskPower's Boundary Dam is the province of Saskatchewan. Boundary Dam was developed as a commercial project to be used for testing only once up and running. This has now been achieved within budget and only at a fraction of the total cost befalling the tax payer. Boundary Dam also has a diverse set of revenue streams, with electricity, CO2 for Enhanced Oil Recovery (EOR), H2SO4 and fly-ash byproducts.

In stark contrast to BoundaryDam is the Mongstad test facility on the Norwegian West coast. The technology centre, is the world's largest and arguably most technologically advanced, but its future utility beyond testing is highly uncertain. And it is currently stuck in a spiral of delays and accumulating costs, with the initial estimated cost having more than quadrupled so far.

SaskPower and the role of smaller-scale projects to instill confidence and public acceptance must not be underplayed. "In my mind, pilots are key to the global implementation of CCS at the moment. They're building our knowledge base and they're key to building public confidence in our technology to get us to larger-scale implementation," Gale said.

As public opposition to CCS in Europe remains high, projects such as Mongstad do not improve the case to convince both the public and investors of CCS projects' viability. Countries like Germany and the Netherlands have especially high opposition levels, with the latter having taken the step to ban onshore CO2 storage, limiting projects to offshore sites.

IEA CCS Technology Roadmap: 2013 update

The energy landscape has shifted between 2009 and 2013 and new insights into the challenges and needs of CCS have been learned, says Maria van der Hoeven, Executive Director of the IEA. The new edition highlights seven key actions needed in the next seven years to create a solid foundation for deployment of CCS starting by 2020.

Between 2009 when the first IEA Carbon Capture and Storage (CCS) roadmap was published, and 2013, the need for CCS has not diminished: the urgency of its deployment has in fact grown, says the IEA in its updated Roadmap.

There have been many developments and significant gains in CCS technology and the enabling policy frameworks. However, given today's level of fossil fuel utilisation, and that a carbon price as a key driver for CCS remains missing, the deployment of CCS is running far below the trajectory required to limit long-term global average temperature increases to 2 °C.

Purpose for the roadmap

The goal of the updated CCS roadmap is to describe and analyse actions needed to accelerate CCS deployment to levels that would allow it to fulfil its CO2 emissions reduction potential. The IEA is revising the 2009 roadmap to reflect developments in CCS that have occurred over the last four years and to develop a plan of action that fully reflects the current context.

Key findings

Carbon capture and storage (CCS) will be a critical component in a portfolio of low-carbon energy technologies if governments undertake ambitious measures to combat climate change.

Given current trends of increasing global energy sector carbon dioxide (CO2) emissions and the dominant role that fossil fuels continue to play in primary energy consumption, the urgency of CCS deployment is only increasing. Under the International Energy Agency (IEA) Energy Technology Perspectives 2012 (ETP 2012) 2 °C Scenario (2DS)[1], CCS contributes one-sixth of CO2 emission reductions required in 2050, and 14% of the cumulative emissions reductions between 2015 and 2050 compared to a business-as-usual approach, which would correspond to a 6 °C rise in average global temperature.

The individual component technologies required for capture, transport and storage are generally well understood and, in some cases, technologically mature.

For example, capture of CO2 from natural gas sweetening and hydrogen production is technically mature and commercially practiced, as is transport of CO2 by pipelines. While safe and effective storage of CO2 has been demonstrated, there are still many lessons to gain from large-scale projects, and more effort is needed to identify viable storage sites. However, the largest challenge for CCS deployment is the integration of component technologies into large-scale demonstration projects. Lack of understanding and acceptance of the technology by the public, as well as some energy and climate stakeholders, also contributes to delays and difficulties in deployment.

Governments and industry must ensure that the incentive and regulatory frameworks are in place to deliver upwards of 30 operating CCS projects by 2020 across a range of processes and industrial sectors.

This would be equivalent to all projects in advanced stages of planning today reaching operation by that time. Co-operation among governments should be encouraged to ensure that the global distribution of projects covers the full spectrum of CCS applications, and mechanisms should be established to facilitate knowledge sharing from early CCS projects.

CCS is not only about electricity generation. Almost half (45%) of the CO2 captured between 2015 and 2050 in the 2DS is from industrial applications.

In this scenario, between 25% and 40% of the global production of steel, cement and chemicals must be equipped with CCS by 2050. Achieving this level of deployment in industrial applications will require capture technologies to be demonstrated by 2020, particularly for iron and steelmaking, as well as cement production.

Given their rapid growth in energy demand, the largest deployment of CCS will need to occur in non-Organisation for Economic Co-operation and Development (OECD) countries.

By 2050, non-OECD countries will need to account for 70% of the total cumulative mass of captured CO2, with China alone accounting for one-third of the global total of captured CO2 between 2015 and 2050. OECD governments and multilateral development banks must work together with non-OECD countries to ensure that support

Seven key actions for the next seven years

The next seven years are critical to the accelerated development of CCS, which is necessary to achieve low-carbon stabilisation goals (i.e. limiting long-term global average temperature increase to 2 °C). The seven key actions below are necessary up to 2020 to lay the foundation for scaled-up CCS deployment. They require serious dedication by governments and industry, but are realistic and cover all three elements of the CCS process.

1. Introduce financial support mechanisms for demonstration and early deployment of CCS to drive private financing of projects.
2. Implement policies that encourage storage exploration, characterisation and development for CCS projects.
3. Develop national laws and regulations as well as provisions for multilateral finance that effectively require new-build, base-load, fossil-fuel power generation capacity to be CCS-ready.
4. Prove capture systems at pilot scale in industrial applications where CO2 capture has not yet been demonstrated.
5. Significantly increase efforts to improve understanding among the public and stakeholders of CCS technology and the importance of its deployment.
6. Reduce the cost of electricity from power plants equipped with capture through continued technology development and use of highest possible efficiency power generation cycles.
7. Encourage efficient development of CO2 transport infrastructure by anticipating locations of future demand centres and future volumes of CO2.

1. #The 2DS describes how technologies across all energy sectors may be transformed by 2050 for an 80% chance of limiting average global temperature increase to 2 °C.

Area	Progress as of 2013
The 2009 CCS roadmap highlighted the need to develop 100 CCS projects between 2010 and 2020, storing around 300 $MtCO_2$/yr.	Four large-scale CCS projects have carried out sufficient monitoring to provide confidence that injected CO_2 will be permanently retained. Collectively, these projects have stored approximately 50 megatonnes of carbon dioxide ($MtCO_2$). Nine further projects under construction together have the potential to capture and store 13 $MtCO_2$/yr. All nine projects should be operational by 2016. Numerous other large projects are in operation and demonstrate one or more technologies in the CCS chain.
The 2009 CCS roadmap suggested that OECD countries will need to invest USD 3.5 billion per year (b/yr) to USD 4 b/yr, and non-OECD countries USD 1.5 b/yr to USD 2 b/yr between 2010 and 2020 to meet the roadmap deployment milestones.	Actual cumulative spending between 2007 and 2012 on projects that demonstrate CCS reached almost USD 10.2 billion. Hence, while spending has been significant, the level targeted by the 2009 roadmap has largely not been met. Government grants contributed USD 2.4 billion of this total. Almost all of this funding is from governments in the United States and Canada (federal and state or provincial). In addition, over the same period a USD 12.1 billion of public funds was made available to CCS.
The 2009 CCS roadmap highlighted the importance of CCS in industrial sectors and called for dedicated actions in specific industrial sectors.	Despite significant activity in some industrial areas, notably gas processing, CCS action in a number of key industrial sectors is almost totally absent (IEA/ UNIDO, 2011). There is a dearth of projects in the iron and steel, cement, oil refining, biofuels and pulp and paper sectors. Only two possible demonstration projects at iron and steel plants, and one at coal-to-chemicals/liquids plants, are at advanced stages of planning (Global CCS Institute, 2013).
The 2009 CCS roadmap presented a vision for CO_2 transport and storage that started with analysis of CO_2 sources, sinks and storage resources, followed by the development of best-practice guidelines and safety regulations by 2020 and leading to a roll-out of pipeline networks to developed storage sites.	Considerable progress has been made in understanding the size and distribution of technically accessible storage resources, factors affecting the cost of storage, and in the development of best-practice recommendations and standards for geologic storage (CSA, 2012; DNV, 2009). The International Organization for Standardization (ISO) has also started a process to develop a series of international standards for CCS. However, much more needs to be done to develop these two elements of the CCS chain to support the scale
Development of comprehensive CCS regulatory frameworks in all countries by 2020 and the resolution of legal issues for trans-boundary transfer of CO_2 by 2012 were identified as key regulatory milestones in the 2009 CCS roadmap.	Some OECD countries (e.g. in Europe; the United States; Canada; Australia) have made significant progress in developing laws ensuring that CO_2 storage is carried out safely and effectively, and are continuing to refine aspects of their frameworks through secondary legislation (IEA, 2012d). Other countries that plan to demonstrate CCS, such as South Africa, are undertaking processes that will lead to comprehensive regulations for CCS. In the area of international law, the 2007 amendment to the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR convention) entered into force in 2011; however, the 2009 amendment to the London Protocol has not yet been ratified by a sufficient number of signatory governments. As an important political development, CCS has also been accepted as a CDM activity under the UNFCCC with related modalities and procedures.

mechanisms are established to drive deployment of CCS in non-OECD countries in the coming decades.

This decade is critical for moving deployment of CCS beyond the demonstration phase in accordance with the 2DS.

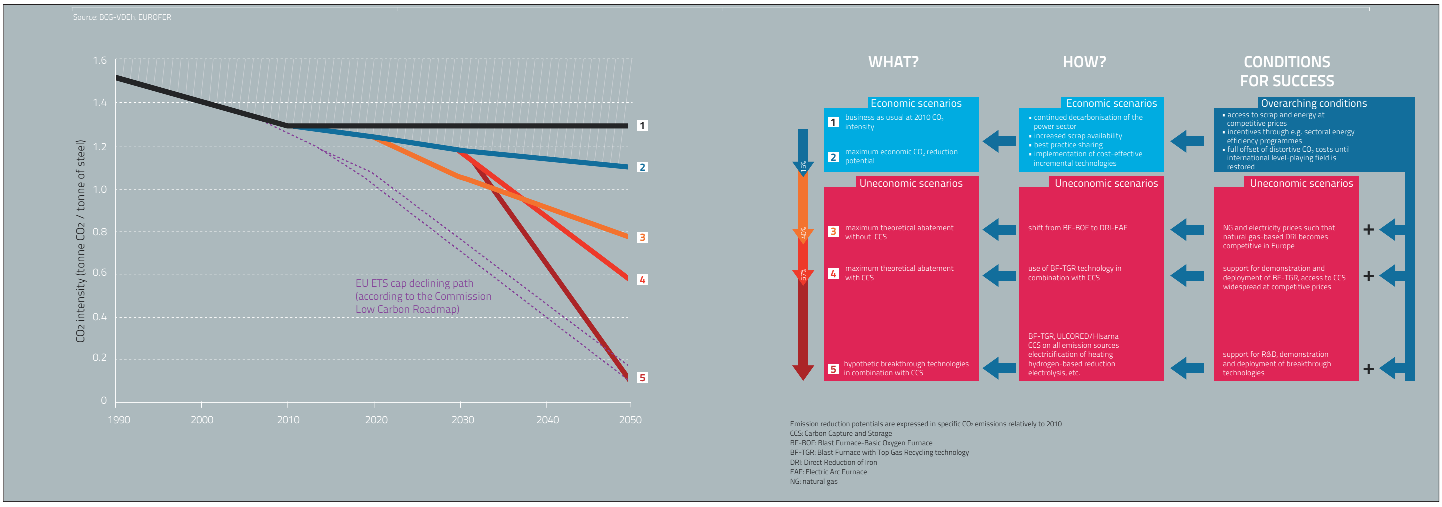
Mobilising the large amounts of financial resources necessary will depend on the development of strong business models for CCS, which are so far lacking. Urgent action is required from industry and governments to develop such models and to implement incentive frameworks that can help them to drive cost-effective CCS deployment. Moreover, planning and actions which take future demand into account are needed to encourage development of CO_2 storage and transport infrastructure.

More information

Download the complete Roadmap at:
www.iea.org

Eurofer presents Steel Roadmap for a Low Carbon Europe 2050

The European Steel industry will be able to reduce its CO2 emissions by an estimated 15 per cent in an economically viable way until 2050 compared to 2010 levels, acccording to the "Steel Roadmap for a Low Carbon Europe 2050."



CO2 intensity pathway scenarios for the EU steel industry up to 2050

The document, produced by the European Steel Association in response to the European Commission's "Roadmap for moving to a low-carbon economy in 2050", pools the results of recent studies on technical and economical potentials for CO2 reduction in steel making. It also looks into possible breakthrough technologies and points out policies which would enable the sector to maintain production in Europe.

The Commission's Roadmap postulates a reduction of 80 to 95 per cent by 2050 compared to 1990 for European industry. The Eurofer Roadmap builds upon the results of a study conducted by the Boston Consulting Group earlier this year, which confirm that this target is far beyond the reach of the steel sector.

The study draws several possible scenarios for CO2 abatement in steel making. In the economic scenario, only 10 per cent emissions reduction per tonne of steel are possible between 2010 and 2030 and 15 per cent between 2010 and 2050. This would be brought about by the use of best available technologies, process optimization and a greater use of steel scrap.

The most promising abatement scenario, theoretically resulting in 60 per cent emissions reductions per tonne of steel between 2010 and 2050, relies on the retrofitting of existing blast furnaces with top-gas recycling technology and full deployment of Carbon Capture and Storage (CCS) in Europe. However, this technology has yet to be proven as technically feasible at industrial scale.

Moreover, to date the economic viability and the general applicability of CCS in Europe appear questionable. Public resistance to CCS in a growing number of Member States as well as the lack of a business case for such a technology make it doubtful that the technology will be applied throughout Europe in the foreseeable future.

Gordon Moffat, Director General of Eurofer: "The steel industry cannot stay in Europe if the Commission's targets are imposed on the sector without further adaptation. In fact, we will not even be able to meet the 2030 intermediate milestone of the EU Emissions Trading Scheme of 43 to 48 per cent reduction as suggested in the Commission's Roadmap. The technologies to do so are not there at present and if they will ever emerge, it will certainly not be on time for the Commission's schedule. It must be acknowledged that sectors like steel cannot follow the decarbonisation path at the same pace than others."

Potential breakthrough technologies

Deep CO2 cuts as postulated in the Commission's Roadmap might be achieved only with radically new and yet unproven breakthrough technologies. The ULCOS research programme (Ultra-Low CO2 Steelmaking), which started in 2004 already, has identified four potential breakthrough technologies. Two of these technologies have been tested on a pilot plant level; none has been demonstrated on an industrial scale yet.

Gordon Moffat: "The EU Emissions Trading Scheme, although some people regard it as a means to incentivise investments in low-carbon technology, will not help here. For making the ULCOS technologies an industrial reality it would take much more than just a high price on emissions allowances.

The massive investments required for demonstration and deployment of these potential technologies clearly exceed our industry's investment capabilities. Therefore, financial support is needed which is consistent with the level of ambition of the EU's climate objectives. This issue should be an integral part of the 2030 Climate and Energy package."

Life-cycle thinking

Following a holistic approach, the Eurofer Roadmap not only looks into possible CO2 abatement in steel production. It also analyses the CO2 mitigation potential from innovative technologies in which steel cannot be replaced by any other material. This analysis was done by Boston Consulting Group, too.

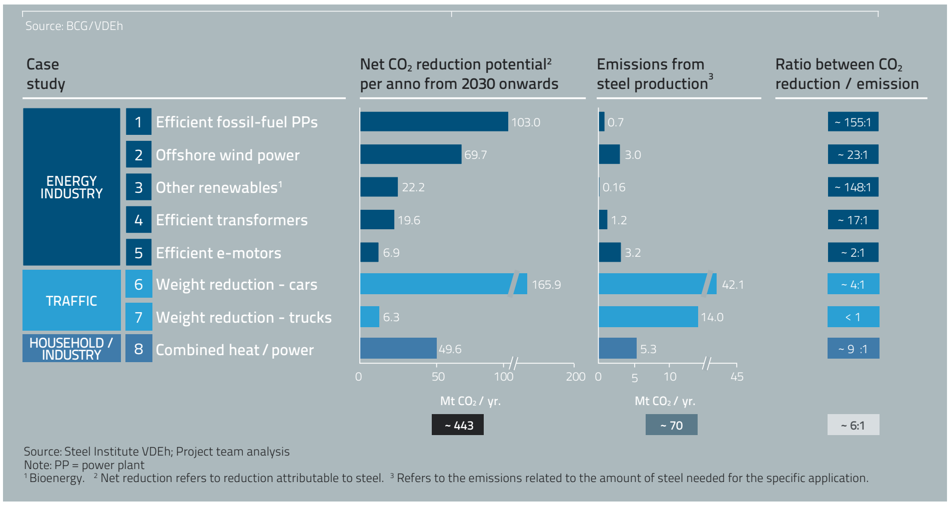
According to case studies on eight se-

lected steel applications, including weight reduced car parts, electric motors or efficiency-improved power plants, the yearly savings would amount to at least 443 million tonnes CO2 in 2030. The prognosis is limited to 2030 because this is a timespan for which the expansion of the technologies looked into can be forecast with sufficient probability.

The amount of 443 million tonnes has to be compared to the emissions released in the production of the steels applied, which amount to only 70 million tonnes. Another comparison: the total steel industry's emissions in 2010 were approximately 220 million tonnes; less than half of the savings potential of only the eight steel applications looked at in the study.

This indicates that European climate targets can hardly be reached without steel. It also calls for a change of perspective on the political level. Current climate policies focus on emissions from the production phase of materials. For steel, this overlooks the material's substantial contribution to climate protection when it is applied in relevant technologies. As yet, European climate policies have no room for this holistic approach, which would also have to integrate the recycling properties of materials.

Gordon Moffat: "Steel is as indispensable for European manufacturing value chains as it is essential for technologies protecting the climate. Unilateral climate action along the mitigation path suggested by the Commission has potentially devastating effects on the EU steel industry. Post-2020 policies should therefore be built bottom-up, taking into consideration technological development. They should also include effective protection against CO2-related costs which jeopardize global competitiveness of the EU industry. Only with a modern, innovative and profitable industry in Europe can the EU's targets for a sustainable, carbon-lean and competitive economy be met."



Case studies for EU27 result in CO2 savings

More information

www.eurofer.be

Symposium at SaskPower Boundary Dam

The inaugural Information and Planning Symposium showcased the knowledge and experience gained from SaskPower undertaking the planning, construction and commissioning of the world's first and largest post-combustion commercial-scale coal-fired CCS project. www.saskpowerccsconsortium.com

The three day program included facilitated technical discussions and a guided tour of the Boundary Dam Power Station and Carbon Capture Facility. Over 100 participants and speakers from 12 different countries attended the Symposium.

Doug Daverne, Director, Carbon Capture and Storage Initiatives, SaskPower, provided the first technical presentation with a focus on the preparatory components that led to beginning construction on the Boundary Dam Unit #3 rebuild and capture facility project. He spoke about the financial investment and time commitment that SaskPower made prior to deciding to proceed with the Unit #3 demonstration project. In his presentation he spoke about:

- Evaluating the feasibility of coal generated electricity integrated with CCS technology on a new unit versus an existing unit;
- Finding out true market costs versus relying on estimates;
- Identifying capture system and refurbishment costs; and
- Comparing costs of coal-fired electricity to natural gas.

Throughout the rest of the day, Symposium participants gained insight on the various activities and groups who have contributed to the project. Topics discussed were:

- Integrated Process Design by SaskPower
- Contract Strategy and Procurement by SaskPower
- Engineering for a CCS Project by Stantec
- Providing the Capture Process by Cansolv Technologies Inc.
- From Engineering, to Procurement, to Construction by SNC-Lavalin Inc.

Day two featured a tour of the Boundary Dam Power Station and Carbon Capture Facility in Estevan, a visit to the Aquistore storage site just two kilometers away from Boundary Dam, and a drive by the Cenovus oil fields near Weyburn where the captured CO2 will be used for enhanced oil recovery.

More presentations on day three included SaskPower project leads providing talks on the power station re-build, operating a capture facility, and future CCS opportunities at SaskPower. The morning session concluded with the introduction to the SaskPower Global CCS Consortium initiative.

Mike Monea, SaskPower President of Carbon Capture and Storage Initiatives, presented the available membership opportunities and the benefits of joining the Consortium. A strong focus of the presentation was how SaskPower's Boundary Dam CCS experiences are transferable to other CCS related projects, and how the knowledge gained from those experiences will have significant impact on planning for future CCS initiatives.

He addressed how Boundary Dam is the first generation of CCS development at SaskPower and that there is already planning in place for the next generation of CCS in Saskatchewan. Preliminary assessments for integrating CCS with Boundary Dam Units #4 and 5 (generation 2, SaskPower CCS Initiatives) have already begun.

ZEP report: CCS in EU energy-intensive industries

The only technology that can provide large-scale emissions reductions in EU energy-intensive industries – such as steel, cement, refineries and chemicals – is CO2 Capture and Storage, says the report.

With direct emissions from EU industries in 2010 accounting for 25% of total EU CO2 emissions and energy efficiency measures insufficient to reduce these emissions significantly, only CCS will enable the EU to deliver its long-term climate goals and retain a strong industrial base.

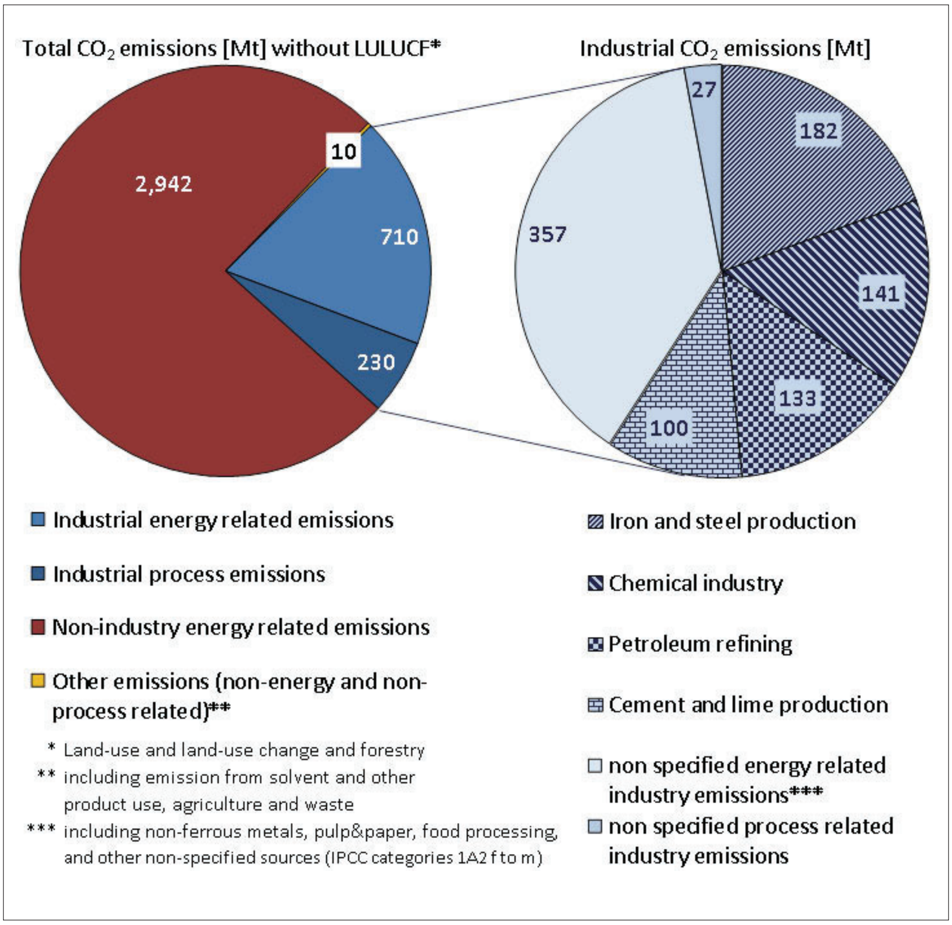
Additionally, industrial sectors need financial support to develop CCS and remain competitive globally.

ZEP strongly backs the Commission in its efforts to support EU industries – not least due to their vital contribution to employment and welfare – but underlines the need to ensure this strategy is well-aligned with EU climate ambitions. According to the EU low-carbon economy roadmap for 2050, emissions reductions will be required in all sectors of the economy, with CO2 emissions from industrial sectors cut by 34% to 40% by 2030 and by 83% to 87% by 2050.

ZEP has therefore been working with energy-intensive industries to develop a landmark report on the role CCS must play in the decarbonisation of their sectors. Published by ZEP today, it provides a high-level overview of the challenges and opportunities – plus a set of recommendations to EU policymakers on how to facilitate large-scale deployment. This includes the need for strong financial support to enable industrial sectors to demonstrate and deploy CCS while remaining competitive globally.

The Zero Emissions Platform (ZEP) therefore welcomes DG CLIMA Director-General Jos Delbeke's support for the large-scale deployment of low-carbon technologies in Europe's energy-intensive industries in his speech at the 2013 European Steel Day. This is a clear signal that the decarbonisation of the EU economy should not happen through the relocation of industry – but through green innovation and technology.

The Commission has followed up with an EU Steel Action Plan, which specifically names CCS as a key decarbonisation technology for the sector and underlines the need for an "industrial scale demonstration project of producing steel with CCS". It also highlights the need for financial support instruments in order to proceed to demonstration and deployment, "for instance a new NER 300 call, a further European Energy programme for Recovery, or the use of structural funds".



Total CO2 emissions and direct CO2 industrial emissions in the EU in 2010 (Using data from UNFCCC National Inventory Submissions, 2012)

Finally, ZEP welcomes signals from the European Parliament's Environment Committee (ENVI) in its latest (19th June) vote on the so-called 'back-loading' of emission unit allowances (EUAs) in the EU ETS.

The ENVI call for two-thirds of the EUAs that the Commission has proposed to remove from the carbon market (and freeze for later auctioning) to be "made available to set up a fund to support the development of innovative low-carbon technologies, demonstration projects and measures intended to reduce the costs and carbon emissions of energy-intensive industries". This aligns with Director-General Delbeke's and the Commission's call to facilitate the demonstration and deployment of CCS in energy-intensive industries.

ZEP says it would welcome continued cooperation between relevant industries, the Commission, other EU institutions and Member States in order to ensure the development of the crucial infrastructure highlighted by Delbeke, identify technology synergies – and ensure an ambitious policy and regulatory framework for large-scale CCS deployment in Europe.

More information

www.zeroemissionsplatform.eu

Policy, projects and regulation news

Bellona promotes revision of EU ETS

www.bellona.org

In its response to the European Commission's Green Paper on a 2030 Framework for Climate and Energy Policies, Bellona has put forward a suggestion to structurally and institutionally revise the EU ETS.

The proposed changes intend to stabilize the price of carbon and thereby create an opportunity for the mechanism to become the major driver towards long term low carbon investment, says Sirin Engen, Bellona

The European Commission's 2030 Green Paper, released on 27 March, invited stakeholders to take part in a consultative process towards the Union's climate and energy policies after 2020. The new policy framework towards 2030 is regarded as an important tool for the EU to reach its target of reducing greenhouse gas emissions by 80-95% by 2050 compared to 1990 levels, as stipulated in the Energy Roadmap 2050. Bellona provided the Commission with its response to the consultation on 2 July.

Bellona emphasized the importance of ensuring that the various measures for climate change mitigation in the EU should be equally supportive. Under the current framework, there is an unfortunate consequence of taking large-scale measures on e.g. energy efficiency or renewable energy deployment, in that those measures reduce the demand for emission allowances (EUAs) and thus reduces the carbon price, in turn undermining the long-term business case for such investments.

The unexpectedly deep and long recession, combined with the interaction with other carbon reduction policies, has led to a significant oversupply of allowances in the market. Climate efforts in the EU are struggling with the current price of carbon; it was forecasted that ETS Emission Unit Allowances (EUAs) would be traded at around or above €30 in 2013. At the time of writing, EUAs are trading at around €4.30/tCO2.

Structural reform of the EU ETS Under the current system, the EU ETS is in practice failing to provide a realistic price on carbon and does therefore not stimulate the upfront investment and innovation necessary to meet the ambitious emissions reductions proposed in the Commission's 2050 low-carbon roadmap.

Because the perception of future scarcity and price stability are important factors for a well-functioning carbon market, Bellona supports a structural reform of the ETS that will allow it to respond to situations of over-supply, as in the current market context. Bellona therefore suggested a reform of the ETS which will establish governance arrangements for optional adjustments to the supply of allowances.

This price-based mechanism ought to be regulated by an independent bank; a European Central Bank of Carbon.

European Central Bank of Carbon Today, adjusting the supply of quotas implies a lengthy political process. "Because addressing climate change is a matter of outmost importance, we believe that the carbon market should be entrusted to an independent regulator to make the necessary decisions to enable the market to function", says Director of Bellona Europa, Jonas Helseth.

"The establishment of a European Central Bank of Carbon will ensure that the ETS reacts swiftly and with flexibility to unpredictable changes in carbon demand and thereby safeguard the orderly functioning of the market", Helseth continues. "This bank must be given a mandate with a view to ensure full decarbonisation at the lowest economical impact in the coming decades toward 2050. In this way, measures to promote green technologies will not undermine the carbon market, but strengthen it", he concludes.

Technology-specific targets Lessons learnt from the 2020 strategy has shown that clear and legally binding targets for technologies can be very valuable, if they are designed to interact properly with other measures. "Bellona therefore supports new and ambitious legally binding targets for 2030 for renewables as well as for energy efficiency and CO2 Capture and Storage (CCS)", says Jonas Helseth; "showing such political will can create early markets for emerging technologies and generate necessary investments to bring down costs that in the future will make Member State funding mechanisms obsolete as the carbon price reaches adequate levels".

CCS A separate communication on CCS was released alongside the Green Paper for climate and energy. Bellona has written responses to both, yet made it clear that the issue of CCS in Europe should not be treated in parallel to other policies but rather as an integral part of the strategy towards 2030.

"At the EU level, Bellona recommends that the Union sets a similar milestone for CCS as it has previously done for renewable energy in order to ensure the political commitment and necessary funding to drive CCS forward in Europe", says Helseth.

Way forward The various responses to the Green Paper from stakeholders all across Europe will now feed into the Commission's on-going preparations for more concrete proposals for the EU's 2030 framework for climate and energy policies, which are expected to be tabled by the end of 2013. The Member States have indicated that they intend to have a political debate with a view to provide some initial conclusions on the Commission's proposals at the European Council in March 2014.

BECCS could lead to climate change reversal

iopscience.iop.org

Bioenergy with carbon capture and storage (BECCS) can reverse the global warming trend and push temperatures back below the global target of 2°C above pre-industrial levels.

This is according to a new study in the Institute of Physics Publishing's journal Environmental Research Letters, which shows that ambitious temperature targets can be exceeded then reclaimed by implementing BECCS around mid-century.

The researchers, from Chalmers University of Technology in Sweden, show that if BECCS is implemented on a large-scale along with other renewable energy sources, temperature increases can be as low as 1.5°C by 2150.

Co-author of the study, Professor Christian Azar, said: "What we demonstrate in our paper is that even if we fail to keep temperature increases below 2°C, then we can reverse the warming trend and push temperatures back below the 2°C target by 2150.

"To do so requires both large-scale use of BECCS and reducing other emissions to near-zero levels using other renewables – mainly solar energy – or nuclear power."

BECCS is a greenhouse gas mitigation technology based on bioenergy that produces fuel for power plants or transportation while simultaneously removing carbon dioxide from the atmosphere. Trees and crops give off carbon dioxide when they are burnt as fuel, but also act as a carbon sink as they grow beforehand, absorbing carbon dioxide from the atmosphere. These two processes cancel each other out, resulting in net zero emissions of carbon dioxide.

When combined with carbon capture and storage – techniques that aim to pull carbon dioxide out of the flue gases from power plants and redirect it into geological storage locations – the overall carbon dioxide emissions are negative. If applied on a global scale, this could help to reverse global warming.

In their study, the researchers devel-

oped an integrated global energy system and climate model that enabled them to assess the most cost-effective way forward for a given energy demand scenario and temperature target.

They find that stringent temperature targets can be met at significantly lower costs if BECCS is implemented 30 to 50 years from now, although this may cause a temporary overshoot of the 2°C target.

"The most policy relevant implication of our study is that even if current political gridlock causes global warming in excess of 2°C, we can reverse the temperature trend and reach targets later. This means that 2°C targets or even more ambitious targets can remain on the table in international climate negotiations," Azar continues.

However, the authors caution against interpreting their study as an argument for delaying emission reductions in the near-term.

Azar says: "BECCS can only reverse global warming if we have net negative emissions from the entire global energy system. This means that all other CO2 emissions need to be reduced to nearly zero.

"Also, temperatures can only be reduced by about 0.6°C per century, which is too slow to act as an 'emergency brake' if climate damages turn out to be too high. The more we reduce emissions now, the more ambitious targets we can achieve in the long term – even with BECCS."

UK research on public attitudes to energy change

www.ukerc.ac.uk

The findings of the study, funded by the UK Energy Research Centre (UKERC) and carried out by a team from the Universities of Cardiff and Nottingham, reveal that people in Britain are fully supportive of the idea of energy system change.

People were unfamiliar with carbon capture and storage (42% of people had never heard of it) and when given further information many expressed concern, viewing it as a "non transition? – a continuation of unsustainable practices associated with fossil fuels.

The research as a whole highlights key factors that influence public assessment of proposed changes. From examining these factors, the research shows that the public favours changes that are: energy efficient rather than wasteful; protect the environment and nature; are reliable, accessible and safe; allow consumers a certain amount of autonomy and power; are socially just and fair; improve on what has gone before; score well in terms of quality and performance; and, fit with a long-term, sustainable trajectory, rather than being just a short-term fix.

The report proposes that energy policies not taking account of these factors in combination are unlikely to secure public support.

Professor Nick Pidgeon, who led the research team, said: "Our participants saw the bigger picture of energy system transformation, and they were overwhelmingly committed to moving away from fossil fuels towards renewable forms of energy production, and to lowering energy demand".

The study synthesis report "Transforming the UK energy system – public values, attitudes and acceptability? brings together the findings from two in-depth phases of research carried out over thirty months; a series of six in-depth deliberative workshops with members of the public held across England, Scotland and Wales; and a nationally representative survey of 2,441 members of the public.

Some of the major findings include:

* In the national survey 74% of participants were very or fairly concerned about climate change, while 82% were worried about the UK becoming too dependent upon energy from other countries.

* 79% wanted to see a reduction in the use of fossil fuels over the next few decades.

* 81% expressed a desire to reduce their energy use; and support for solar (85%) and wind energy (75%) remained very strong.

* The public is undecided on the role of nuclear power in the future energy mix. However, over half (54%) still said they would oppose the building of a new nuclear power station in their area.

* Awareness of new low-carbon technologies for the home, such as "heat pumps?, was low. The percentage of people willing to use electric heating rose from 42% to 61% if it was posed as matching the performance of current systems, and to 85% if it was also presented as cheaper. A majority (53%) were willing to use electric vehicles, rising to 75% if they performed as well as conventional models.

* There were mixed views about smart metering and so-called "demand side management? – where use of new information technology helps to promote energy efficiency and reduction measures. Here, notions about the home being a private space, free from outside control, were important. People were also more open to the idea of appliances being turned off automatically after a period on standby, for example, than they were about having their showering times curtailed or their fridges and freezers controlled remotely.

* Whilst most people were willing to share their electricity data, around a fifth (22%) were not. Interestingly, people were more willing to share data about their electricity use with energy companies than with the Government, who they perceived to be motivated by short-term motives related to the electoral cycle rather than a genuine desire for change.

* Neither energy companies nor Government were trusted, and the research indicates that this issue must be addressed for successful energy system change.

Professor Pidgeon comments: "Our research has shown clearly that people are more likely to accept changes that show signs of commitment to their underlying values, such as energy system components that are clean, efficient, fair and safe. The public is also keen for policy makers to clarify how current changes to the energy system fit with longer-term plans, and to develop an intelligible and coherent strategy for this".

Low carbon gas from mixed waste, biomass and coal: a low cost route to CCS

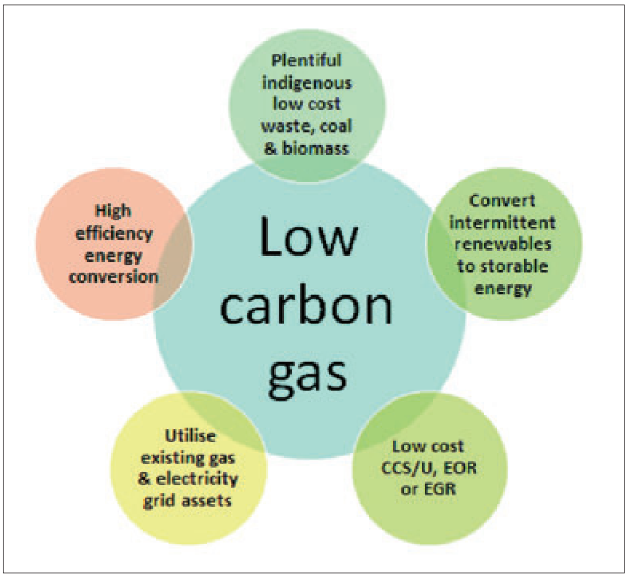
This article is based on a paper by Dr. Williams at the 2012 IChemE gasification conference and describes an approach to integrating low carbon gas into the supply grid as a route to low cost CCS

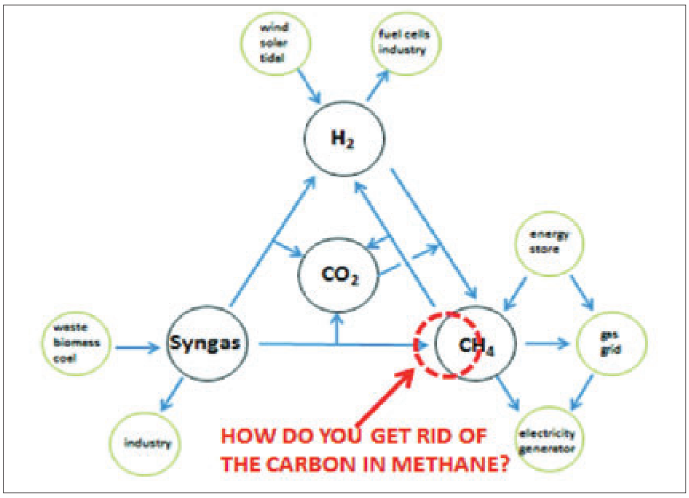
By Tony Day consultant cost benefit analyst; Dr. Williams of GL Noble Denton Ltd, and Chris Hodrien of Timmins CCS Ltd.

British Gas (BG) developed high efficiency coal to Synthetic Natural Gas (SNG) technology between 1955 and 1992. Costly British coal made SNG uneconomic compared with cheap North Sea gas. Replacing coal by low cost waste makes SNG economically competitive. 60 bar negative emissions LCG produced for 40 to 45 p/therm, less than the cost of Natural Gas, will enable gas users, and existing CCGT's, to be decarbonised at zero cost.

SNG making is inherently carbon capture ready. CO2 separation and compression is standard gas industry practise. High pressure LCG made by co-gasifying partly biogenic mixed waste, biomass and coal, using the integrated ex-BG SNG and high CO2 partial pressure Timmins CCS processes, produces supercritical CO2 by-product for 40p/tonne. Per unit energy output, 3 to 4 times less CO2 is produced by LCG than CCS on fossil power generation. Supercritical CO2 produced in smaller quantities, at lower cost, is more useful for enhanced oil, gas and Coal Bed Methane recovery, 'dry' fracking and CCU than large quantities of expensive CO2 from fossil power generation.

The three main gaseous energy vectors are: Synthesis Gas (Syngas), Hydrogen and methane. Of these, methane is the most useful, providing the backbone of the UK energy system. Delivering decarbonisation policy targets at reasonable cost requires the substantial decarbonising of gas supplies. This possibility is explored in this article.





Methane: the ideal gaseous energy vector. How do you get rid of the carbon atom in the methane molecule?

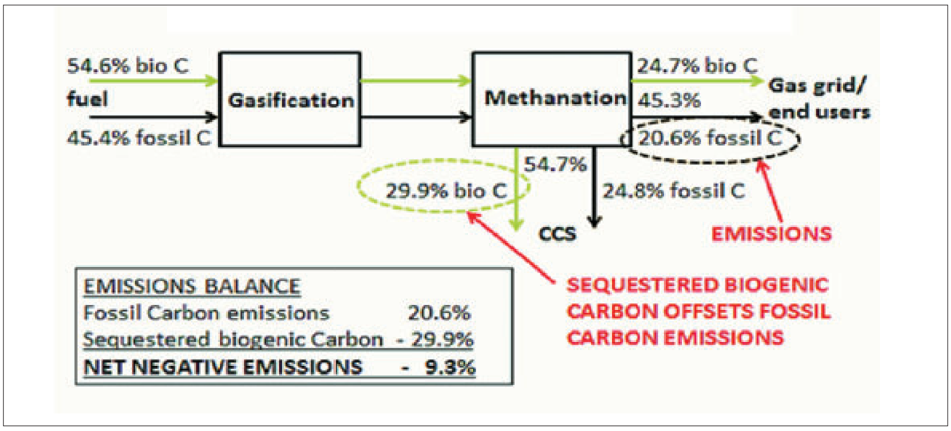
Off-setting the carbon atom in the methane molecule

Low Carbon Gas (LCG) is made by combining the methanation of 50+% biogenic mixed part biogenic and part fossil fuels, with CCS. Sequestering sustainably sourced biogenic CO2 removes anthropogenic CO2 from the Earth's atmosphere.

The negative emissions from sequestering biogenic carbon are used to offset fossil carbon emissions. Biogenic carbon emissions and sequestered fossil carbon are accounted as emissions neutral. The waste CO2 by-product of methanation used for CCS is typically over 50% of the total Carbon throughput. Combining 50+% biogenic fuel and 50+% CCS produces negative net emissions of anthropogenic CO2.

Gt. Plains Synfuel plant produces commercially viable SNG from lignite. Inherently carbon capture ready methanation produces waste CO2 by-product for commercial EOR. Replacing part of the lignite fuel at Gt. Plains with low cost mixed wastes and biomass would economically decarbonise the product SNG to produce LCG.

Injecting low cost high pressure LCG into the gas grid decarbonises existing



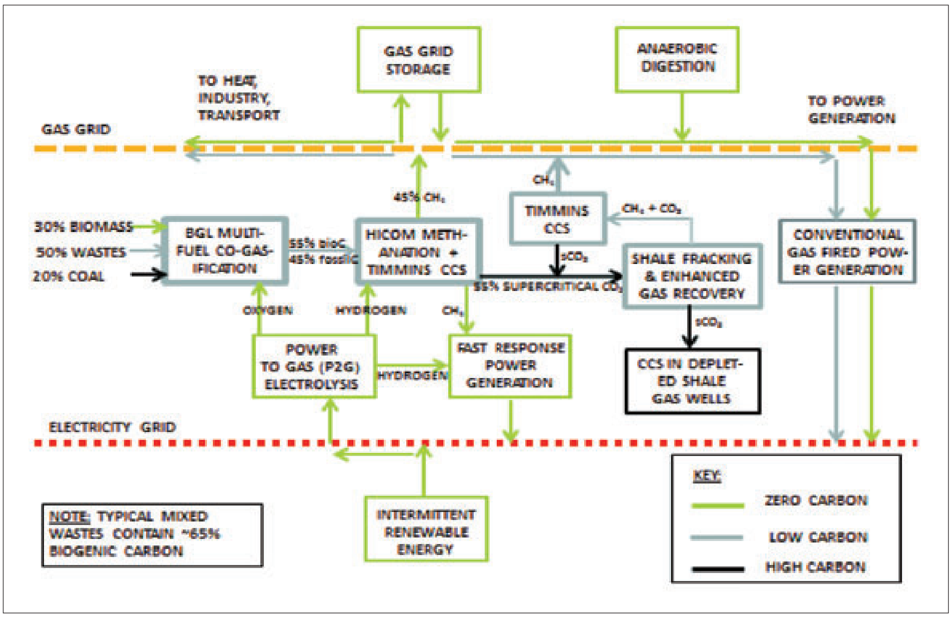
Low carbon gas

CCGT's at zero operational cost, or loss of load factor. CCGT's can be geographically distributed, with LCG plants grouped near CCS 'hubs'. Carbon capture ready unabated LCG plants can easily be abated when a supercritical CO2 'hub' or pipeline becomes available. LCG can support low cost Power to Gas and intermittent renewable energy storage. Low cost supercritical CO2 can support 'dry fracking', enhanced oil or shale gas recovery and CCS in depleted shale gas wells providing an onshore gas industry method of reducing the cost of decarbonising energy supplies, and the cost of CCS. Integrated methane synthesis with CCS is the key 'hub' technology to deliver low carbon gas and power.

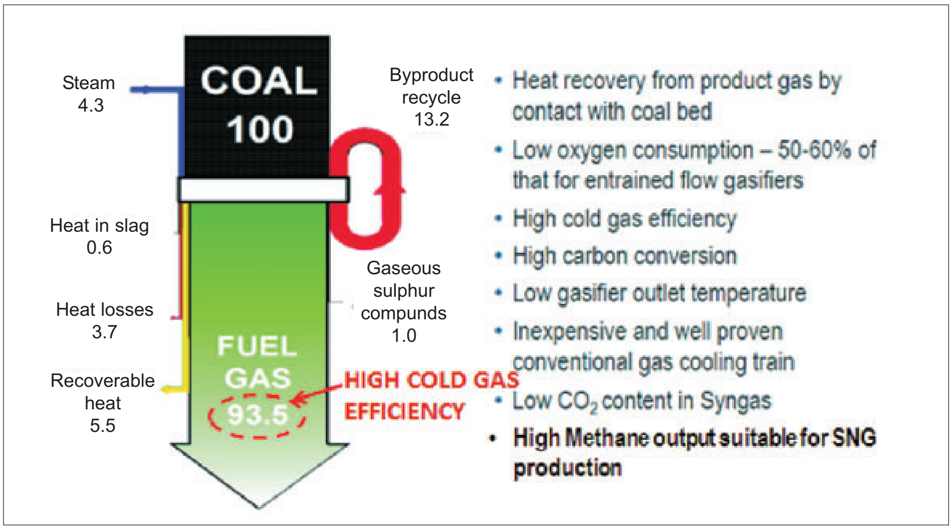
Reducing the cost of synthetic gas

The cost of synthetic methane is dependent on:

- Efficient process design.
- Fuel cost.
- Cost of capital.
- Economies of scale.



Injecting low cost high pressure LCG into the gas grid



British Gas: world's highest cold gas efficiency solid multi-fuel gasifier

Process efficiency

BG's cost studies indicate that for a given process, and cost of fuel and finance, the output cost of SNG was dependent on plant size and process pressure. BGL gasification at 65 bar pressure was demonstrated at Westfield in the 1980's. BG estimated that gasifying coal at 80 bar would produce 60 bar SNG at 76% efficiency unabated. The BGL gasifier produces high methane content Syngas. Increasing gasification pressure, and replacing coal by the plastic in waste, increases methane yield and reduces the work to convert Syngas to methane

A recent 4 year proof of concept study, using commercially confidential ex-BG cost and engineering data, indicates that integrating proven high efficiency BG methanation technology operating at 70 bar with waste based fuels, and Timmins CCS, produces 60 bar pipeline ready negative emissions LCG, and dry 99.6% pure 150 bar supercritical CO2, at a net efficiency of 76.75%. This must be one of the few cases where the use of low grade secondary fuels, and adding CCS, increases the efficiency of the underlying unabated technology.

The economics of methane synthesis

SNG production is established technology, its economic viability depending on the price 'spread' between the fuel and Natural Gas. Due to the large 'spread' between low cost stranded West China coal and expensive East coast LNG imports, inter-connected by low cost gas pipelines, SNG production in China is developing rapidly.

The Lurgi dry ash gasifier was developed during the 1930's. The first pilot of its derivative the slagging Lurgi gasifier was built in 1943 to gasify Italian lignite. In 1947 HM Ministry of Fuel and Power reported that the economic case for the slagging gasification of low grade fuel lay in the fuel cost being low enough to cover the cost of oxygen. In 1955 the Ministry purchased the rights to the slagging Lurgi gasifier, now called the British Gas Lurgi or BGL gasifier.

This uses less steam and oxygen than the dry ash version. The future of gasification in Europe lies in gasifying low grade secondary fuels. The diversion of large quantities of waste from landfill has turned residual waste into a useful low cost fuel. The 'spread' between the unit cost of low cost mixed wastes, biomass and coal, and the unit cost of fossil Natural Gas makes SNG production in EU and UK economically viable.

Reducing the cost of sustainable gas

The avoided cost of 2015 UK Landfill Tax at £-8/GJ offsets the cost of coal and biomass at around £2.25 to £4.0/GJ producing a near zero cost 50+% biogenic fuel mix. The 'spread' between waste at £-8/GJ and Natural Gas at around £6.25/GJ makes converting waste to gas financially attractive. Using some coal in the fuel mix to provide the energy to drive slagging gasification is far more economic than using electricity to drive plasma gasification.

The projected 40 to 45 p/therm (£15/MWh) unit cost of 60 bar storable LCG at from high CO2 partial pressure LCG making with CCS is around 1/6th the projected £100/MWh unit cost of CCS on low CO2

partial pressure fossil fuel power generation. The 40p/tonne unit cost of supercritical CO2 (sCO2) from an LCG plant with Timmins CCS is around 2 orders of magnitude lower than for fossil fuel power generation. The cost per unit energy of sCO2 transport and storage from an LCG plant is around ¼ to 1/3rd the cost per unit energy of sCO2 transport and storage from CCS on fossil fuel power generation.

Co-gasifying approximately 50% mixed secondary fuels: residual hazardous and non-hazardous residential, commercial and industrial wastes; Refuse and Tyre Derived Fuel; petcoke; sewage and industrial sludges; 30% contaminated and woody biomass, and 20% coal or briquetted lignite reduces input fuel costs to near zero, and contains nearly 55% biogenic carbon, delivering LCG and CCS at lower cost than any other fuel/technology mix.

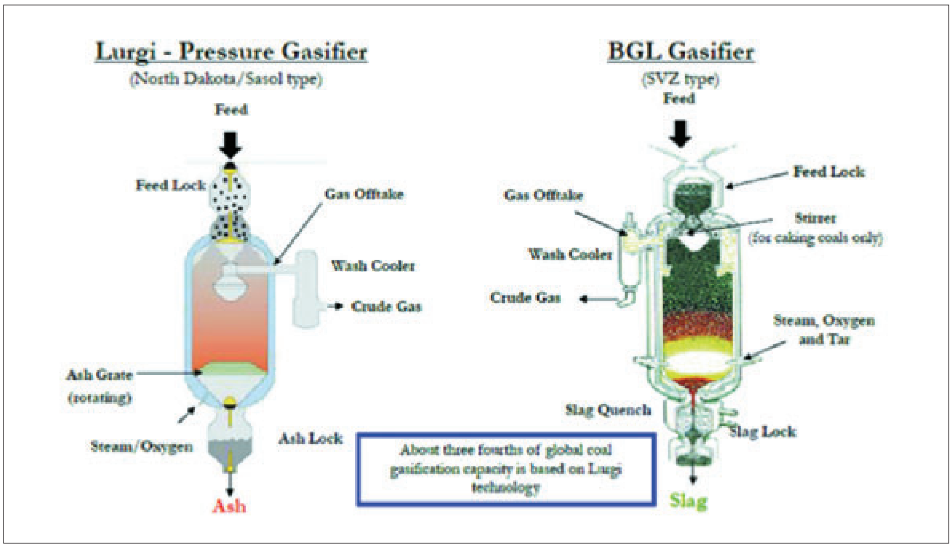
British Gas synthetic gas developments

When the UK gas grid was converted from Towns Gas to Natural Gas, it was known that the different properties of the two gases would make re-conversion to Towns Gas impractical. It was unclear whether UK possessed sufficient Natural Gas to supply its needs, and how long it would last. Supported by HM Government, BG embarked on a strategic long-term programme to develop SNG against a future shortage of Natural Gas.

BG "High Speed Gas" naptha to SNG conversion was commercialised in USA. Pulverised coal hydrogenation to SNG was demonstrated at test rig scale. Commercial scale high efficiency BGL slagging gasification and HICOM combined catalytic shift and methanation of lump or briquetted coal to SNG technology was developed between 1955 and 1992 The SNG development plant at Westfield was mothballed on completed of the R and D programme.

Co-gasifying waste, biomass and coal using the BGL gasifier was demonstrated commercially at SVZ Schwarze Pumpe between the late 1980's and 2007. Gt. Plains has been converting lignite to SNG since 1984 using Lurgi dry ash gasifiers, with CCS for EOR since 1999. Westfield, Gt. Plains and SVZ were always inherently carbon capture ready.

Different elements of the LCG process chain were developed at the plants, but the whole chain was not demonstrated at a single plant. Except for this accident of history, large scale low cost LCG might have been commercialised 30 years ago. BGL gasifiers are being built in China to use low grade stranded North China coal assets. HICOM catalysts are used at Great Plains and the recently completed Phase 1 SNG plant at Datang.



British Gas slagging gasifier based on proven Lurgi dry ash gasifier: high efficiency due to low steam and oxygen use

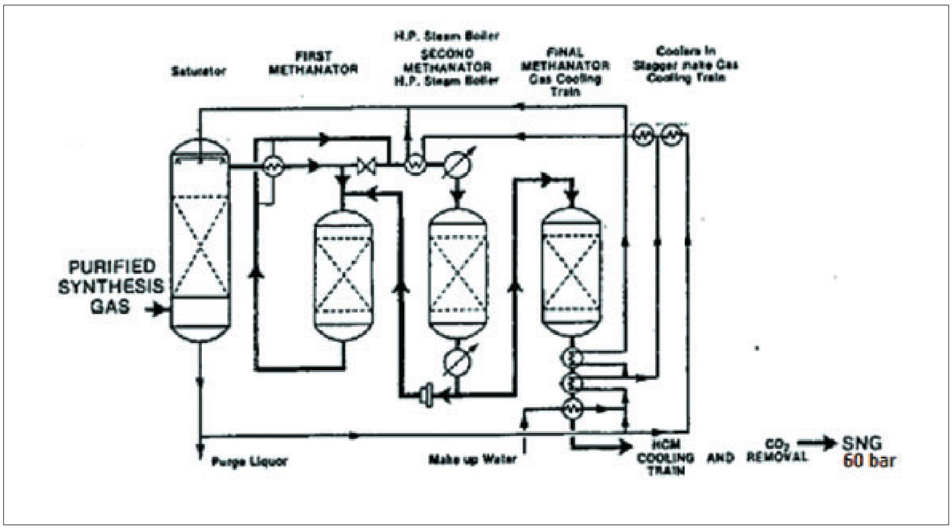
High efficiency thermo-chemical mass and energy transfer

Both the BGL gasifier and HICOM combined shift and methanation use internal mass and energy transfer to maximise process energy efficiency. Carbon is oxidised to provide the energy to drive the gasification and methanation reactions. During gasification and methanation, oxygen and steam are injected into the process gas stream.

The hydrogen to oxygen molecular bond in the steam is broken, and the hydrogen re-bonded to carbon, producing methane. CO2 is separated to leave the methane product gas. Hydrogen and oxygen are added to the process gas stream, and CO2 is removed. In essence, carbon to hydrogen mass and energy exchange occurs.

The BGL is counter-current gasifier. Hot Syngas flows upwards from the gasification zone at the bottom of the gasifier causing the fuel being fed by gravity from the top of the gasifier to be dried, pre-heated, devolatilised and pyrolised prior to gasification. The Syngas is cooled from around 2000 to 5000C. Internal heat exchange reduces the need for external Syngas cooling and heat exchange, and increases process efficiency.

HICOM combined catalytic shift and methanation combines two exothermic reactions. This reduces the requirement for external heat exchange, and maximises exothermic energy recovery to high temperature and pressure steam used for power generation and process utilities. The shift reaction absorbs water. The methanation reaction produces water. Internal water exchange occurs between the shift and methanation reactions. This reduces steam injection and downstream water vapour removal.



British Gas HICOM high efficiency combined shift and catalytic methanation process

The importance of CO2 partial pressure

IPPC, IEA, UK CCSA and Schlumberger state that CO2 partial pressure (CO2 concentration x pressure) is the 'key' determinant of CO2 capture and compression cost, which is 80% of the cost of CCS. CO2 solubility in a carrier liquid is a function of gas pressure. The volume flow rate of gases, and vessels, pipe and pump size, is a function of gas pressure. CO2 concentration determines the amount of gas to be processed to obtain a given amount of CO2.

For the same energy input, the CO2 partial pressure in an SNG plant with Timmins CCS is 250 times greater, and the gas volume flow rate 400 times less, than in a fossil fuel power plant with post-capture CCS. This massive engineering and cost benefit is due not to any 'magic', but to basic process physics and chemistry.

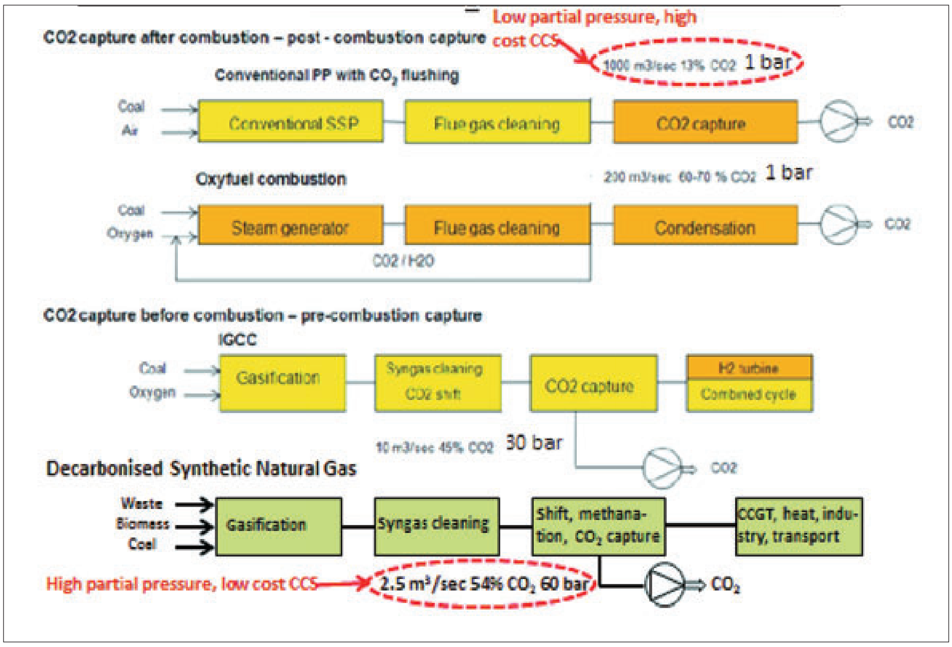
Timmins CCS

Cyril Timmins led the BG SNG commercialisation programme. His co-patentee, Keith Tart was co-patentee for HICOM. The Timmins CCS recycle loop is a generic process for reducing the cost of separating CO2 from mixed gas streams at over 10 bar gas pressure. The efficiency penalty of CO2 separation and compression is reduced by running the whole plant at high pressure, with no pressure let-down.

The cost of cryogenic separation is reduced by separating half the CO2 at each pass. The part CO2 content gas mix is recycled back into the process using the incoming process gas as 'stripping gas'. The CO2 recycle loop is the basis for the patent, and is applicable to any process separating CO2 from high pressure mixed gases.

The Timmins CCS process is an elegant 'fit' with high pressure HICOM combined shift and methanation. In the integrated process, the high CO2 partial pressure assists in inhibiting the harmful Boudouard reaction (2CO = C + CO2). The recirculated CO2 assists gas cooling during exothermic methanation. Cryogenic separation of part of the CO2 stream reduces the work done by the Selexol plant. The volume flow rate of the process gases is 400 times less, and the CO2 partial pressure is 240 times greater, than post combustion CCS on fossil fuel power generation.

In the unabated LCG with Timmins CCS case, dry 99.6% pure liquid CO2 is produced at 60 bar. In the abated case, the energy penalty to pump cool liquid CO2 to 150 bar supercritical state is only 0.06%. This leads to the Marginal Abatement Cost of Carbon capture and compression of £0.4/tonne, excluding transport and storage costs.



Comparative CCS CO2 partial pressures

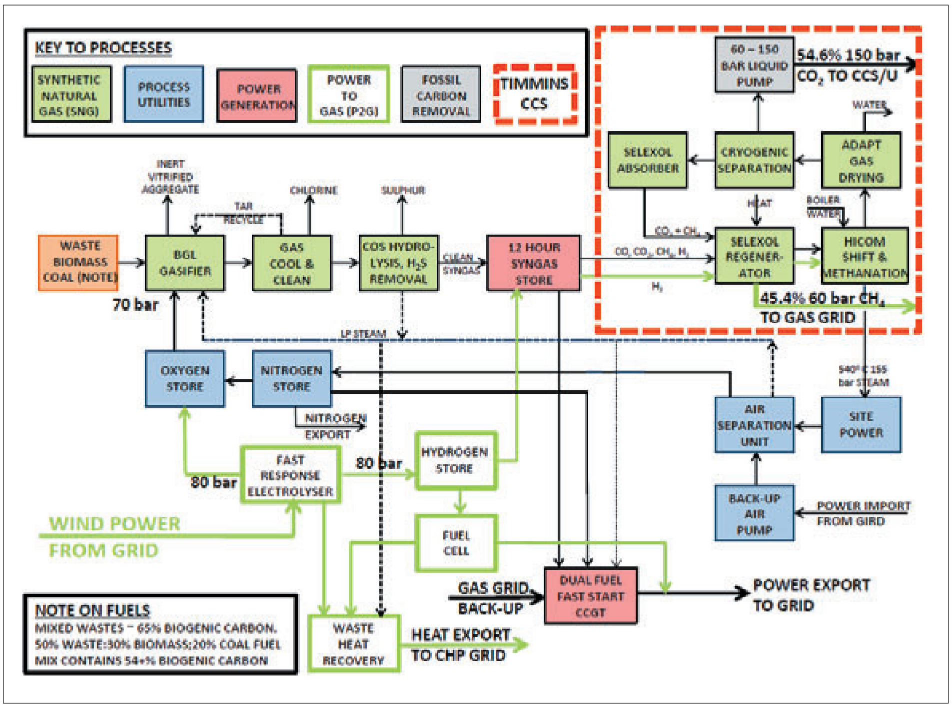
Technology	Low carbon gas (LCG)	Post capture coal	Oxyfuel coal	Pre capture IGCC
Gas flow	2.5 m3/sec	1000 m3/sec	200 m3/sec	10 m3/sec
CO2 partial pressure	32.4 bar	0.13 bar	0.65 bar	13.5 bar

Comparative gas volumes and CO2 partial pressures

The transport and storage cost of CO2 per unit energy is 25 to 33% that for CCS on fossil fuel power generation.

Comparative costs of power generation with CCS

CCS Association's recently reported on re-



Power to gas and intermittent renewable energy storage with CCS

ducing the whole system cost of CCS on power generation. Using the CCSA's published data, and LCG production cost analyses, the 'whole system' cost (including transport and storage) of power from LCG is around 1/3rd the cost of CCS on fossil fuel power generation. The whole system cost per tonne of CO2 from LCG is between 5% and 10% of CCS on fossil fuel power generation.

Spin-off uses for low cost LCG and supercritical CO2 production (P2G, EOR/EGR, CCS/U)

Gasification technology is highly flexible. Clean Syngas supports numerous downstream uses for Syngas. Low cost LCG, low cost supercritical CO2 and 'green' Hydrogen can support a variety of clean energy technologies.

Power to gas and intermittent renewable energy storage

LCG production uses both the hydrogen and oxygen produced by P2G plants, and the existing gas grid for economical bulk renewable energy storage and transmission. Injecting hydrogen into HICOM increases methane production and reduces CO2 production.

Less steam is required for the shift reaction; less excess steam has to be removed after methanation, and exothermic heat output increases. Oxygen from electrolysis reduces the load on the air separation unit. LCG plant efficiency is increased for the same fuel input and plant CAPEX. The enhanced Return on Capital Employed for the LCG plant can be used to offset the low ROCE for the P2G plant.

'Dry' fracking, enhanced gas recovery (EGR) and enhanced coal bed methane recovery (ECBR)

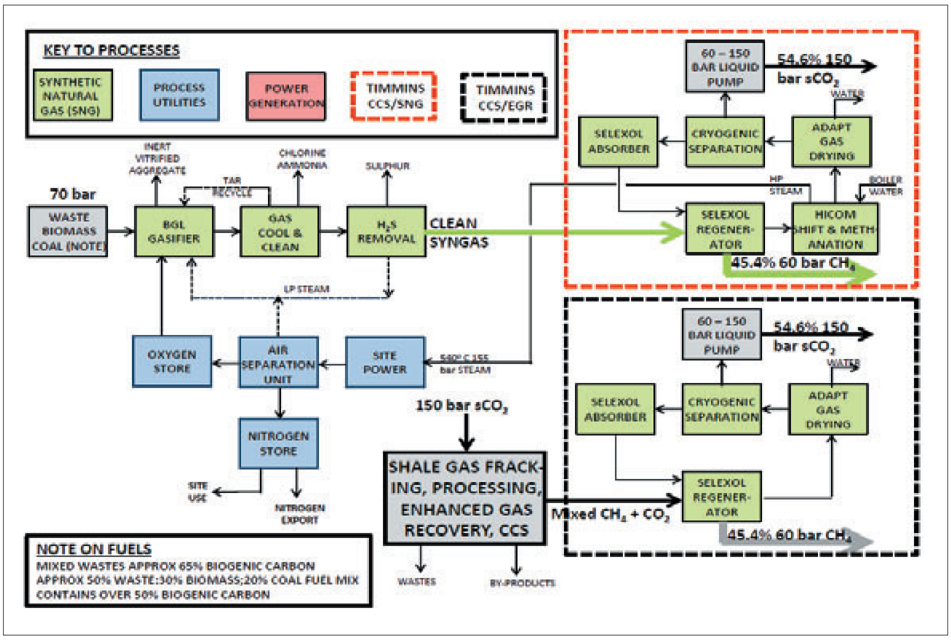
Low cost supercritical CO2 can be used for: drilling; enhanced shale 'dry' fracking and proppant; EGR by methane desorption, reservoir re-pressurisation and 'sweep' gas, and CCS in depleted conventional and unconventional oil and gas wells. Most Natural Gas reservoirs contain some CO2, which must be removed in order to meet gas quality standards. Timmins CCS can be used for gas removing CO2 returned from conventional gas, EGR and ECBR.

Making CCS into an economic proposition

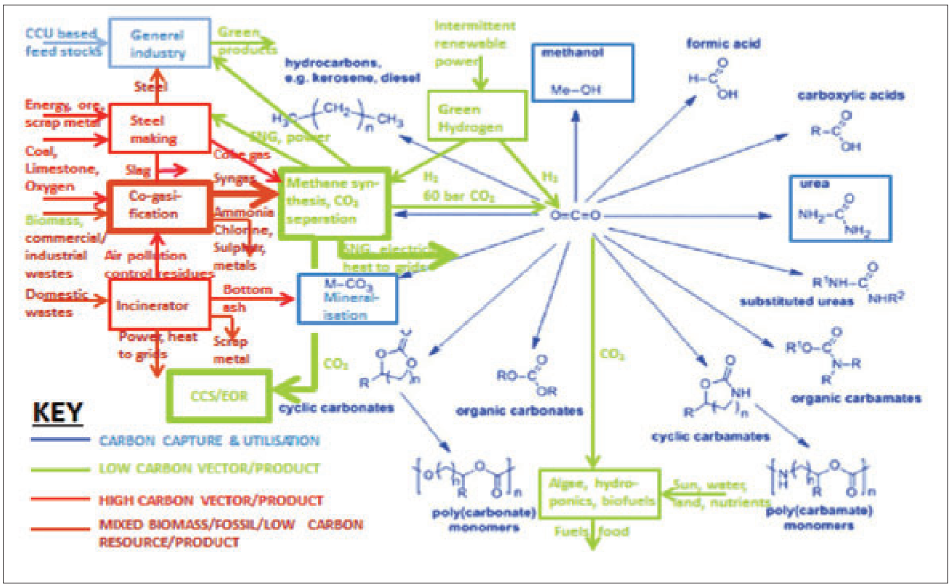
Making economic use of supercritical CO2 for EOR and EGR depends critically on matching supercritical CO2 supply and demand to raise the revenue to pay for CCS infrastructure. A typical large UKCS oil field uses around 2 to 3 mtpa of supercritical CO2 for a period of around 5 years, reducing by around 50% after 5 years.

A 1GWe fossil fuel power station produces around 6 mtpa of CO2, but this may fluctuate dramatically depending on the balance of electricity supply and demand in the grid. A 1 GWSNG LCG plant produces around 1.75 mtpa of CO2, and will operate largely at constant throughput as the gas grid operates as an effectively infinite capacity energy store.

This will enable supercritical CO2 supply and demand by the UKCS oil and gas industry to be balanced against supercritical CO2 production from LCG more easily than for fossil fuel power generation.



'Dry' fracking and enhanced gas recovery with CCS



SNG hub integrates energy grids and storage, CCS/U, biofuels, steel and industry

Carbon capture and utilisation (CCS/U)

Low cost LCG derived from waste and industrial sources, low cost high purity CO2 produced by Timmins CCS, and 'green' hydrogen can support a wide variety of chemical and biological synthesis routes to produce a variety of low carbon products, foods and energy vectors. Some of the more promising of these are shown above. In this concept, Syngas, hydrogen and LCG production are integrated around the 'core' methane synthesis and CCS.

More information

Tony Day
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Capture and utilisation news

Novel solvent for CO2 capture receives patent

uanews.ua.edu

An innovative method capturing CO2 from industrial emissions is potentially cheaper and more efficient than current methods, according to a United States patent based on research by Dr. Jason E. Bara, assistant professor of chemical and biological engineering at The University of Alabama.

Many commercially-available CO2 capture methods use a liquid solution of water and amine to absorb the gas. The system patented by Bara would replace much of the water in the aqueous amine solutions with a promising class of molecules known as imidazoles, organic solvents with a low vapor pressure, or boiling point.

The patent, granted earlier in August to UA, claims the chemical make-up of the imidazole-containing systems for use in capturing CO2 and other gases from natural gas and post-combustion emissions such as those from coal-fired power plants.

"The advantages of imidazoles in carbon capture are that they are a class of solvents with tunable chemical and physical properties," Bara said. "This gives us a lot of flexibility in designing a solvent system that can meet process demands."

One of the most common commercially used and most studied solvents is monoethanolamine, or MEA. The use of MEA to scrub flue gas is energy intensive since recycling the solution requires boiling it to desorb, or rid, the CO2before recycle of the MEA solution back into contact with the flue gas. The cost of the energy needed to use MEA in power plants, for example, would likely be passed onto consumers, Bara said.

Bara's work shows that swapping most of the water in the process with imidazoles saves energy since the solvent can be regenerated without the energy penalties associated with boiling large amounts of water. Bara's research shows the solvent system can capture the same or more CO2than MEA.

The cost of capturing carbon is one reason the energy industry has been reluctant to embrace carbon capture on a large scale. "That's why it is important to look at solvents and materials that are tweaks to what are already established if we hope to do very large scale up over the next decade," Bara said.

"What's really nice about this solvent system is that we're not starting from scratch," he said. "Many imidazole cores are already commercially available, and through some very simple reactions, we can synthesize the molecules we want in the lab. This should bode well in terms of solvent cost if we were to scale them up."

Research led by Dr. Jason E. Bara shows a more efficient and cheaper method for capturing carbon dioxide

This technology has been licensed to the clean tech company ION Engineering in Boulder, Colo., with the hope of further developing this technology for carbon dioxide capture. Bara helped found ION Engineering, and continues as a science adviser with the company.

Bara's research is funded by the U.S. Department of Energy, the National Science Foundation and the American Chemical Society Petroleum Research Fund.First CO2 captured in ADEME, Alstom and EDF project

The first tonne of CO2 has been captured at the EDF power plant in Le Havre, France.

www.alstom.com

The project was awarded funding by the French Environment and Energy Management Agency (ADEME) in 2010.

This pilot is installed in unit 4 at the EDF thermal power station in Le Havre. The technology, provided by Alstom in partnership with The Dow Chemical Co. and chosen by EDF, consists in cleaning the flue gas with UCARSOLTM FGC-3000 amine solvent from Dow, which is the base component of the reagent used to separate CO2 from the flue gas. For this pilot unit, Alstom and Dow have deployed an advanced configuration for the process, specifically developed to minimise energy consumption.

The objective, using this research prototype, is to capture about 1 tonne of CO2 per hour. The CO2 will be released into the atmosphere, the aim of the project being to test the CO2 capture process itself and not the storage. Following technical testing, EDF will analyse the cost implications of the process.

A dozen engineers from the Research and Development teams at EDF and Alstom are driving the tests. The intent of these tests is to confirm the predicted quantity of energy and amine solvent required to operate the unit, so as to assess whether the process is worthwhile from a cost and an environmental standpoint. They will also look at how the unit performs in an industrial setting, as well as how flexible it is to use within a fully operating power plant. Such tests represent a crucial step in developing efficient industrial solutions for capturing CO2.

Akermin pilot completes 1600 hours of CO2 capture

www.akermin.com

The pilot plant using biocatalytic technology completed 1,600 hours of operation capturing CO2 from the flue gas exhaust of a coal-fired power plant.

Since Akermin initiated operation of the pilot plant with its Biocatalyst Delivery System in May 2013, the unit has consistently captured over 80% CO2 from the flue gas exhaust. During this period, it has operated with no biocatalyst replenishment while demonstrating significant rate enhancement,

the company said.

"We are thrilled with the impressive results of our pilot testing," said Alex Zaks, VP of Research and CTO at Akermin. "The 1,600 hours of operation without any degradation in performance clearly demonstrates the ability of the biocatalyst to operate for extended durations without the need for replacement. This brings Akermin one step closer to commercial introduction."

Akermin is currently developing and testing a next generation approach that uses an environmentally-friendly solvent and proprietary process scheme with on-line biocatalyst replenishment. This approach has the potential to reduce the avoided cost of capture by as much as 40% versus the solutions that have recently been evaluated for commercial-scale demonstration on coal-fired power plants throughout North America and Europe, the company claims.

In addition, Akermin looks to commercialize the technology in the near-term to treat industrial gas streams for biogas upgrading, LNG liquefaction and ammonia production. This will position the company to progressively scale-up the technology to provide a cost-effective and environmentally-benign solution to capture CO2 from large industrial plants and fossil-fired power plants to better address the global issue of managing CO2 emissions from industrial processes.

CO2 Solutions says its enzyme technology cuts CCS costs by a third

www.co2solutions.com

CO2 Solutions says it has demonstrated that its enzyme-enabled carbon capture technology is at least one-third less expensive than existing carbon capture technology in terms of energy consumption

The company also said it has shown that the technology can withstand the rigors of industrial application.

The project will now proceed to the large-bench scale (0.5 metric ton/day CO2 capture) testing phase for the remainder of 2013 where the same performance metrics will be validated under flue gas conditions. Following successful large-bench validation and, according to the current schedule, the project will move to field pilot-scale (approximately 15 metric tons/day CO2 capture) testing in 2014, CO2 Solutions says.

CO2 Solutions' enzymatic technology yielded an energy cost reduction of at least 33 percent compared to existing carbon capture technologies when employed to capture 90 percent of the CO2 emissions from natural gas combustion at a typical in-situ oil sands operation, the company says. The 33 percent cost reduction was achieved without any process optimization, and the company expects further savings upon optimization and operational integration in later development phases.

The project target was to demonstrate a cost reduction of 25 percent relative to existing carbon capture technologies.

The company says the selected solvent is also better for the environment compared to other methods.

The project shows that CO2 Solutions' patented enzyme-accelerated process can be deployed efficiently at low temperatures, which can simplify process configuration and shows the solvent's longevity, the company says.

RTI partners with Norcem for cement carbon capture

www.rti.org

RTI International and Norcem, part of HeidelbergCement Group, are partnering to carry out a pilot-scale carbon dioxide capture technology demonstration project in Norcem's cement plant in Brevik, Norway.

Under terms of the three-year project, RTI will adapt and integrate its solid sorbent-based process technology, currently being developed for coal-fired power plants, into the cement plant.

If successful, RTI's technology may provide the cement industry a viable CO2 mitigation option. Because cement plants are large point sources of CO2 emissions, cement manufacturers are seeking cost-effective methods for capturing CO2 emissions. For nearly a decade, RTI has been developing novel process technologies to efficiently capture CO2 using funding provided by the U.S. Department of Energy (DOE), targeted mainly at coal-fired power plants.

The solid sorbent-based technology is currently being developed in collaboration with Pennsylvania State University and is supported through a cooperative agreement with the DOE's National Energy Technology Laboratory (NETL). Co-funding is provided by Masdar in the United Arab Emirates, which is interested in the potential application of this technology for natural gas-fired power plants.

"Our solid sorbent-based technology has the potential to substantially reduce the process energy load and costs compared to conventional liquid solvent CO2 scrubbing technology," said Tom Nelson, RTI's project manager. "Because the operating experience of cement plants is largely based on solids handling, we think it is an excellent fit for the cement industry."

Under the project, the team will first develop a commercial design of the solid sorbent CO2 capture technology for a typical cement plant, then conduct a detailed techno-economic study to show the feasibility of this technology, and finally demonstrate, on a small pilot scale, the efficient removal of CO2 at Norcem's plant.

Carbon Clean Solutions completes solvent testing

www.carboncleansolutions.com

The company has successfully completed commercial testing of its proprietary CDRMax® carbon dioxide capture solvent technology.

Carbon Clean Solutions' (CCS) 22MTPD (metric tons per day) plant, or 7700 tons per annum CO2 capture plant, where the technology is being operated since August 2012, is owned by Solvay Chemicals and is located in India.

The CDRMax® solvent enabled capture of CO2 from a slipstream of flue gas for over 2500 hours, far more than the norm for industrial testing. "The Solvay plant testing has exhibited the robustness of CCS's technology, which requires almost no modifications to the existing setup", remarked Prateek Bumb, the Chief Technical Officer of CCS.

The flue gas, which originates from a kiln source, contains impurities like high SOx content, NOx (upto 45ppm), particulate matter and high oxygen content. Compared to the technology previously being used at the plant, the CDRMax® solvent required over 10 times less make-up solvent replenishment, consumed 7 times less water, and resulted in increased solvent life by 3 times, leading to savings of $23 per ton of CO2 captured.

"The main advantages are lower specific energy consumption by about 30% compared to conventional technology and high O2 tolerance level" said Mr. Tirthankar Mitra, MD Solvay Vishnu Barium.

The CCS technology can be retro-fitted to existing installations, and has been independently evaluated by third parties such as TNO as among the best in the market currently.

"The commercial validation has supplied a wealth of data and proof that the technology can be easily scaled up 10-20 times to be fitted into 200-400 MTPD plants. The consistent capture of CO2 from the rapidly changing input gas showcases the technology's utility in a variety of applications, ranging from industries which require CO2 as input for downstream processes, to power plants which want to reduce emissions and even in biogas up-gradation into natural gas", said Chief Executive Officer, Anirudha Sharma.

ICO2N report assesses climate impact of using CO2 for enhanced oil recovery (EOR)

A new report, prepared exclusively for the integrated CO2 Network (ICO2N) by the Pembina Institute, analyzes the onsite and downstream GHG emissions from using CO2 for enhanced oil recovery.

The study, “Net Greenhouse Gas Impact of Storing CO2 through Enhanced Oil Recovery”, focuses on analysing the on-site and downstream GHG emissions from CO2-EOR crude oil production in Western Canada and does not take upstream emissions from the capture and transport of CO2 into account.

Considering five different scenarios representing differing viewpoints the analysis attempts to quantify these various perspectives. The scenarios are presented such that they build upon each other.

The first scenario starts when a tonne of CO2 arrives on site and there is straight geological storage.

As a second scenario there is an analysis of the stored CO2 at an EOR site as well as the onsite emissions.

As a third scenario the full lifetime emissions for EOR are taken into account; this refers to the downstream emissions associated with the oil produced through EOR.

And as fourth and fifth scenario the oil produced through EOR is assumed to displace other oil in the marketplace, this is done for both a barrel of oilsands crude and the average barrel in the North American market. In this step the full lifetime emissions of EOR plus the GHG savings of displacing oil in the market place are accounted for.

“There are multiple perspectives on how people view the GHG impact of CO2-EOR,” notes Eric Beynon, Director of Strategy and Policy at ICO2N. “This is a unique study that aims to bring quantitative analysis to these perspectives to help support dialogue and stimulate discussion around this topic.”

As the impact of storing CO2 through EOR varies greatly depending on perspective and by project the analysis did not attempt to arrive at an absolute conclusion however the following high level conclusions were drawn out:

- When assuming oil produced through the EOR process fully displaces competing sources of crude oil, EOR has a GHG benefit.

- The ratio of CO2 injected to barrels of oil produced has a large impact on the overall GHG benefit of CO2-EOR.

- On a lifecycle GHG intensity basis and oil produced from EOR falls in between comparative North American sources of oil.

SCENARIO	DESCRIPTION	QUESTION BEING ADDRESSED
S1: Geologic Storage (CCS)	Net[2] CO_2 storage through geologic sequestration: On-site operations[3] of permanent CO_2 injection into a saline aquifer.	How much CO_2 is stored in a scheme where CO_2 is stored in deep geologic formations and not used for any other purpose?
S2: EOR On-Site	Net CO_2 storage through EOR: On-site operations[4] of CO_2 injection into a depleted oil reservoir.	What is the net CO_2 stored in an EOR operation including the impact of recycling CO_2 for EOR and other onsite activities?
S3: EOR system-wide emissions	Net CO_2 emissions associated with EOR on-site activities[5] (S2) as well as downstream emissions (production, transport, refinement, combustion) associated with the barrel of oil produced.	What are GHG emissions of an EOR project including the downstream impacts of the produced barrels of oil?
S4: EOR system-wide emissions with offsetting of barrel of oilsands	Assessing the lifetime emissions of EOR (S3) with the added assumption that oil produced from EOR will offset the production and use of a barrel of oil from the oilsands (50% mineable, 50% in-situ).	What is the net GHG impact of a barrel of oil produced through EOR in the context of global oil supply? Specifically what is the net impact of a barrel of EOR oil replacing a barrel of oilsands in the North American market?
S5: EOR system-wide emissions with offsetting of average barrel	Assessing the lifetime emissions of EOR (S3) with the added assumption that oil produced from EOR will offset the production and use of an average barrel that is processed in the United States.	What is the net GHG impact of a barrel of oil produced through EOR in the context of global oil supply? Specifically, what is the net impact of a barrel of EOR oil replacing another ‘average’ barrel in the North American market?[6]

Overview of scenario and question being addressed (perspective)

2 “Net” refers to the total GHG impact to the atmosphere.

3 On-site operations for geologic sequestration includes the small amount of energy use for monitoring, measurement, and verification (MMV) and fugitives at site.

4 On-site operations for EOR includes injecting, producing, recycling, and processing the CO2 and emulsion along with flaring, venting and other onsite emission sources associate with oil production.

5 “On-site activities” refers to field operations.

6 “Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels”, National Energy Technology Laboratory, November 26 2008.

More information

The Integrated CO2 Network provides technical, scientific and advocacy leadership surrounding the deployment of CCS worldwide and in Canada.

www.ico2n.com

Transport and storage news

National Grid has completed test drilling to appraise a storage site off the East coast of the UK

National Grid completes test drilling for North Sea CO2 storage site

www.nationalgrid.com

National Grid has successfully completed test drilling of a carbon dioxide storage site in the North Sea – a major milestone in delivering a storage solution for CCS.

Early indications are that the undersea site 65 kilometres off the Yorkshire coast is viable for carbon dioxide storage and will be able to hold around 200 million tonnes permanently. This is equivalent to taking ten million cars off the road for 10 years.

The drilling is a major milestone in its Don Valley storage work programme funded by an EU grant to advance CCS in Europe. The findings are significant as this type of storage site is common in Europe.

Peter Boreham, National Grid's director of European Business Development said:

"Global energy demand is likely to double in the next twenty years and CCS is the only technology that can turn high carbon fuels into genuinely low carbon electricity and keep costs low for consumers".

"Drilling is part of a programme which confirms our confidence that CCS will be a practical part of tomorrow's energy mix".

"Within Europe, the UK is in a good position to lead on CCS with clusters of industry and power stations that are near to large storage sites like this one in the North Sea. Progress has been supported by an EU grant and this will enable further analysis on the samples we've collected."

Power stations and industry in the Humber region create about 10% of total UK emissions. Captured carbon dioxide from this cluster of emitters could be taken in shared pipelines and stored in the North Sea storage site. National Grid would use its expertise in developing, constructing and operating gas pipelines to create a network to transport carbon dioxide.

The recent test drilling will provide additional data to confirm the volume that the site can hold and the rate that CO^2 can be injected.

Finding "Goldilocks" sites for CO2 storage

www.pnas.org

To implement carbon capture and storage successfully, each underground repository will need careful appraisal based on its unique history and setting, according to a new study co-authored by researchers from the University of Bristol.

In 2000, one of the first commercial appraisals of CO2 geological storage was begun in Weyburn, Saskatchewan Province, Canada where approximately 3 megatonnes of CO2 are successfully sequestered every year. Scientists at Bristol have played a key research role in developing methods for monitoring the CO2 migration and storage in the reservoir.

In a paper published today in the Proceedings of the National Academy of Sciences, Dr James Verdon and colleagues from Bristol, the Geological Survey of Canada, the British Geological Survey and BP Alternative Energy compare results from the world's three largest CCS projects. Their study finds that not all sites are equal and successful implementation of CCS requires careful appraisal.

For the approach to work the gas must remain trapped for thousands of years, but some geoscientists have argued that the injection process could increase the pressure enough to open fractures that will allow the CO2 to escape.

To address this concern, Dr Verdon and colleagues examined the 'geomechanical deformation' at three commercial-scale CCS sites that inject more than a megatonne of CO2 underground per year: Sleipner Field in the Norwegian North Sea; Weyburn Field in Central Canada; and the In Salah Field in Algeria. The authors found that these three sites have each exhibited very different responses, highlighting the need for systematic geomechanical appraisals prior to gas injection.

Whilst showing no signs of leakage, the Weyburn site has shown a complicated response, due to a history of 50 years of oil production prior to CO2 injection. At the In Salah site, slower fluid flow means that pressures can build up, and there is evidence for fracturing in and around the reservoir, and uplift of several centimetres at the surface has been seen from satellite monitoring. The size of the Sleipner site, and the excellent flow properties means that approximately 1 megatonne of CO2 can be stored every year with little response from the subsurface.

This variability of response means that future large-scale CCS operations will need to conduct comprehensive and on-going monitoring to ensure continued integrity of underground storage sites, according to the authors.

Dr Verdon said: "Existing commercial CCS sites have shown that, from a technical perspective, it is possible to sequester CO2 in underground rocks. However, to make a dent in mankind's total emissions, billions of tons of CO2 must be stored every year. The challenge is therefore to find 3,000 more sites just like Sleipner.

"Every future CCS site will have a different geological setting, and our study has shown that this can lead to very different responses to CO2 injection. There is not likely to be a 'one-size-fits-all' approach to CCS. Instead, each future site must be judged on its merits: some may be very effective for storing large volumes of CO2, but some may be more limited in the amount of CO2 they can take."

Co-author Dr Mike Kendall added:

"This study underscores the importance of long-term monitoring at any CCS storage site. Regulators have yet to impose long-term seismic monitoring guidelines that are necessary to ensure secure storage."

The research was supported by the Natural Environment Research Council (NERC grants NE/I010904/1 and NE/I021497/1) and the Petroleum Technology Research Council of Canada.

ZEP report warns EU must invest €2.5B in CO2 transport infrastructure

www.zeroemissionsplatform.eu

A report published by the Zero Emissions Platform (ZEP)warns that unless the EU urgently invests in transport infrastructure for CCS technology, it will fail to meet its climate change goals.

The European Commission's recent Communication on CCS stated that CCS is "vital for meeting the Union's greenhouse gas reduction targets." Large-scale CCS requires an infrastructure capable of transporting 100s of millions of tonnes of CO2 every year – from power plants and heavy industry to storage sites, across the whole of Europe. However, due to long lead times – 6 to 10 years to build facilities such as pipelines and storage sites – development must start now, ahead of wide-scale deployment of CCS.

Commenting on the report's findings, ZEP Chairman, Dr. Graeme Sweeney, said: "Without urgent investment in CO2 infrastructure – at least €2.5 billion by 2020 – the EU will fail to meet its own climate change targets. The cost of delay will be massive. A 10 year delay in the deployment of CCS will increase the global costs of decarbonising the power sector alone by $1 trillion."

The report makes it clear that it is vital to exploit the enabling power of properly planned CO2 infrastructure – with CO2 hubs, networks and emissions clusters providing the essential foundations for wide-scale CCS deployment.

Urgent political action is needed to overcome current barriers to investment. The report recommends five key actions for governments:

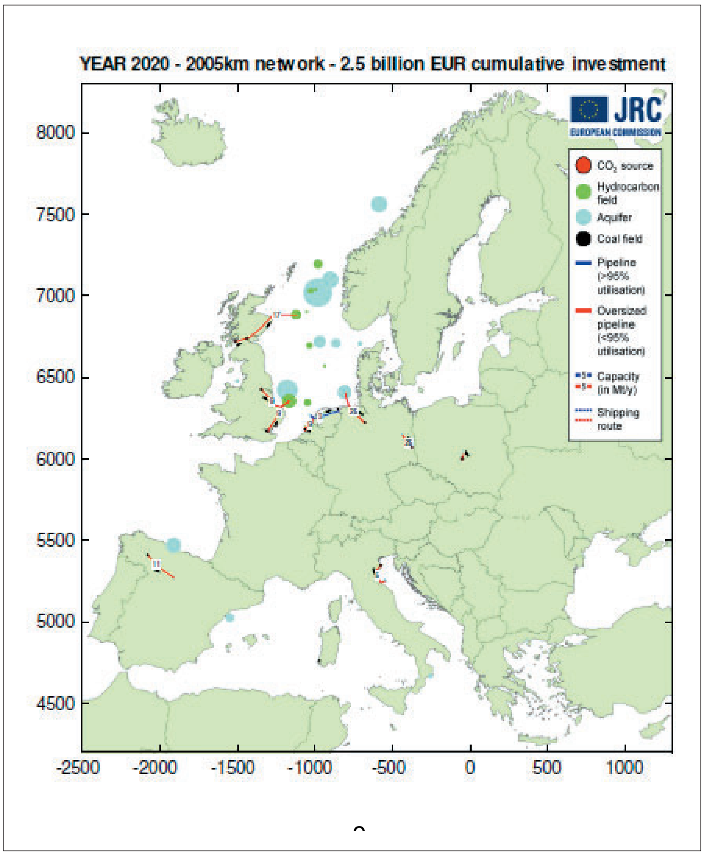
· Establish short-term incentives beyond the EU ETS to de-risk investment for early movers.

· Provide funding to aid the development of CO2 infrastructure in its own right – not tied to a specific capture plant.

· Make funding for CO2 infrastructure an integral part of the EU Energy Infrastructure Package – especially for CCS projects serving emissions clusters. These should be termed projects of 'Common Interest' as even those located wholly in one Member State will facilitate wider deployment.

· Waive third-party access requirements for early movers until clarity on this issue is achieved.

· Member States which have yet not ratified OSPAR and London Protocol amendments should do so urgently in order to enable cross-border CO2 transport and storage, where necessary.



ZEP report - Scenario identified by the EU's Joint Research Centre for the development of a trans-European CO2 transport network

GCCSI webinar on incentives for CO2-EOR

www.globalccsinstitute.com

Options for incentivising large–scale CCS projects in budget constrained times were outlined in "Proposed incentives to promote capture and use of carbon dioxide (CO2) for EOR".

Held on 25 June 2013, the webinar covered the possible use of tax credits linked to CO2–EOR/CCUS to incentivise early–mover large–scale projects.

Large–scale projects are needed to advance CCS and reduce its cost through 'learning by doing', said the Institute. The current lack of incentives, coupled with high capture costs, discourage the entry of new large–scale projects in the planning pipeline and make it difficult for existing projects to reach a financial investment decision.

Patrick Falwell, a Solutions Fellow for the Center for Climate and Energy Solutions, outlined the proposal put forth by the National Enhanced Oil Recovery Initiative. Ben Yamagata, Executive Director of the Coal Utilization Research Council (CURC), discussed CURC's concept.

Both organisations propose a tax credit tied to the use of captured CO2 for EOR. They estimate that the government investment would be recouped within 10 years through tax and royalty revenue received on additional oil production and that the scheme would become revenue-positive to government after this time.

State of play of geological storage of CO2 in 28 European countries

The report "State of play on CO2 geological storage in 28 European countries", published in the framework of the Pan-European Coordination Action on CO2 Geological Storage (FP7 CGS Europe project), reflects the current situation and achievements regarding geological storage of CO2 in the 28 European countries covered by CGS Europe.

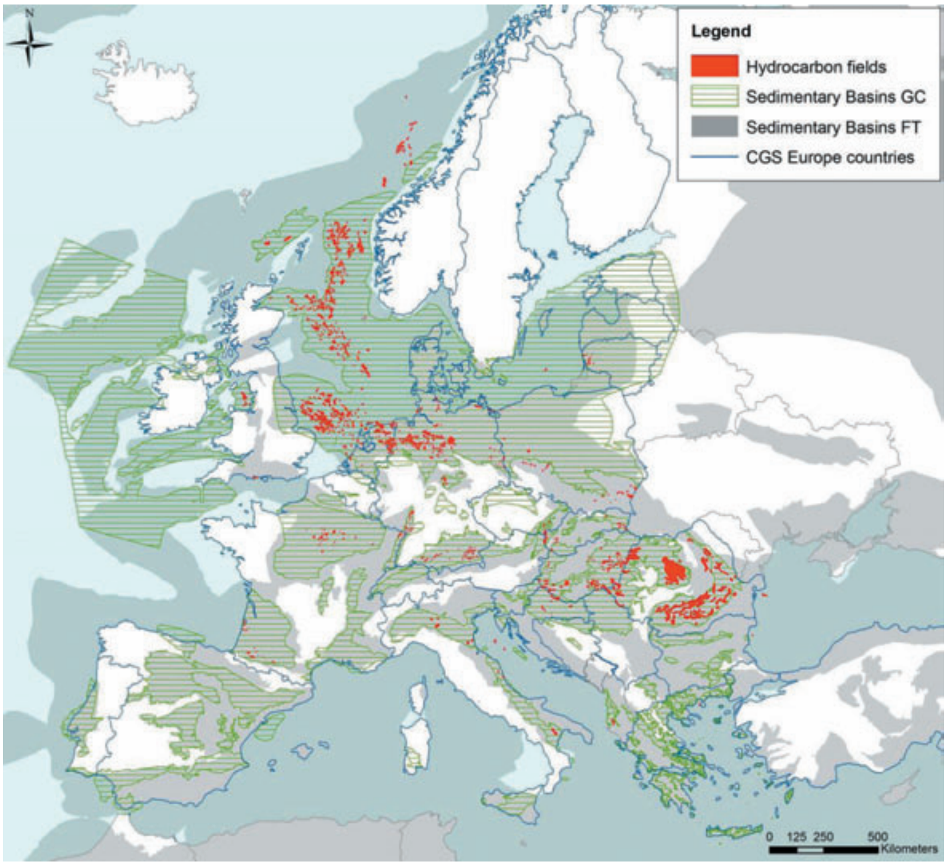
The European Commission recently took the first step towards developing a 2030 framework for EU climate change and energy policies. The Commission also published a Consultative Communication on the future of CO2 capture and storage (CCS) in Europe, aimed at initiating a debate on the options available to ensure its timely development. In parallel, The European Parliament is preparing a report on developing and applying CCS Technology in Europe.

The report gives a brief overview of the CO2 storage options, potentials and capacities in Europe. It summarizes information on research activities and organization of research funding related to CO2 storage in each of the CGS Europe countries.

Information on a national level is complemented by an overview of activities on a regional and European level. Current pilot, demo and test sites in the CGS Europe countries are listed, followed by an overview of the state of transposition of the EU Directive on the geological storage of CO2 and the level of public awareness in the individual countries.

For a Europe-wide comparison, a ranking is provided assessing the overall national achievements regarding CO2 storage in the 28 European countries. The current level of CCS activities in European Countries varies widely between well advanced countries, such as Norway, and CCS-rejecting countries that have not even transposed the EU CCS Directive into national law. CGS Europe exchanges geo-technical knowledge between advanced and following countries in order to level the playing field and pave the way for the future deployment of CO2 storage pilot and demonstration projects in Europe.

The report is a valuable information pool for the current debate on the future CO2 Capture and Storage in Europe. The CO2GeoNet Association, the European network of excellence on CO2 geological storage, in close connection with the CGS Europe FP7 project, here expresses the views of a pan-European consortium involving 34 research institutes from 24 EU Member States and 4 Associated Countries. As such representing the European scientific community on CO2 Geological Storage (CGS), CO2GeoNet and CGS Europe wish to share their expert input for the debate on taking CCS forward in Europe.



Extent of sedimentary basins (in grey: Fugro Tellus (FT), 2008; in shaded green: GeoCapacity (GC), 2009) and potential hydrocarbon fields for CO2 storage in Europe (GeoCapacity, 2009). CGS Europe countries are marked by blue borderlines. Note that countries that are completely surrounded by CGS Europe countries, but are not member of CGS Europe, also appear with blue borderlines as is the case for Switzerland, Luxemburg, San Marino, The Vatican State, Lichtenstein, Monaco and Andorra

About CO2GeoNet

CO2GeoNet is the European scientific body on CO2 geological storage. Founded by 13 public research institutes from 7 European countries, it brings together over 300 researchers with the multidisciplinary expertise needed to address all aspects of CO2 storage. With activities encompassing joint research, training, scientific advice, information and communication, CO2GeoNet has a valuable and independent role to play in enabling the efficient and safe geological storage of CO2. As of 2013, the membership of CO2GeoNet is expanding thanks to the support of the FP7 CGS Europe project. More about CO2GeoNet at :
www.co2geonet.eu

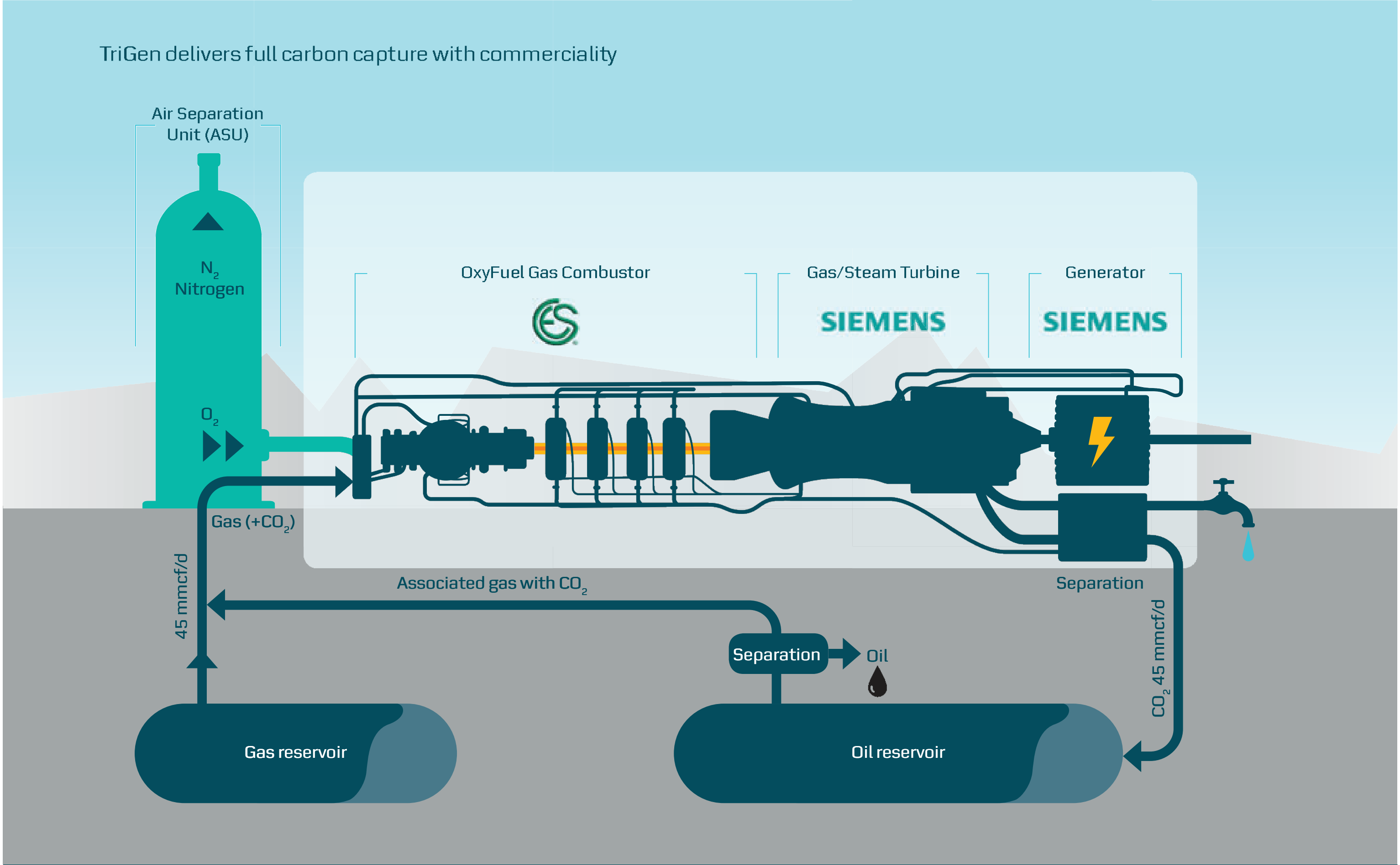
Status of CCS projects

The status of large-scale integrated projects data courtesy of the Global CCS Institute

For the full list, with the latest data as it becomes available, please download a spreadsheet at:
www.globalccsinstitute.com/data/status-ccs-project-database

Asset Lifecycle Stage	Project Name	Description
Operate	**Century Plant**	Occidental Petroleum, in partnership with Sandridge Energy, is operating a gas processing plant in West Texas that at present can capture 5 Mtpa of carbon dioxide for use in enhanced oil recovery. Capture capacity will be increased to 8.5 Mtpa in 2012.
Operate	**Enid Fertilizer CO2-EOR Project**	Since 1982, the Enid Fertilizer plant has sent around 680,000 tonnes per annum of carbon dioxide to be used in enhanced oil recovery operations in Oklahoma.
Operate	**Great Plains Synfuel Plant and Weyburn-Midale Project**	About 3 Mtpa of carbon dioxide is captured from the Great Plains Synfuel plant in North Dakota. Since 2000 the carbon dioxide has been transported by pipeline into Canada for enhanced oil recovery in the Weyburn Field, and since 2005 in Midale Field.
Operate	**In Salah CO2 Storage**	In Salah is a fully operational CCS project in Algeria. Since 2004, around 1 million tonnes per annum of carbon dioxide are separated from produced gas, transported by pipeline and injected for storage in a deep saline formation.
Operate	**Shute Creek Gas Processing Facility**	Around 7 million tonnes per annum of carbon dioxide are recovered from ExxonMobil's Shute Creek gas processing plant in Wyoming, and transported by pipeline to various oil fields for enhanced oil recovery. This project has been operational since 1986.
Operate	**Sleipner CO2 Injection**	Sleipner is the second largest gas development in the North Sea. Carbon dioxide is separated from produced gas at Sleipner T and reinjected into a deep saline formation above the hydrocarbon reservoir zone. This project has been in operation since 1996.
Operate	**Snøhvit CO2 Injection**	The Snøhvit offshore gas field and related CCS activities have been in operation since 2007. Carbon dioxide separated from the gas produced at an onshore liquid natural gas plant is reinjected into a deep saline formation below the reservoir zones.
Operate	**Val Verde Natural Gas Plants**	This operating enhanced oil recovery project uses carbon dioxide sourced from the Mitchell, Gray Ranch, Puckett, Pikes Peak and Terrell gas processing plants and transported via the Val Verde and CRC pipelines.
Operate	**Air Products Steam Methane Reformer EOR Project**	This project is capturing more than 1 million tonnes per year of carbon dioxide from two steam methane reformers, transported via Denbury's Midwest pipeline to the Hastings and Oyster Bayou oil fields for enhanced oil recovery.
Execute	**Alberta Carbon Trunk Line ("ACTL") with Agrium CO2 Stream**	Agrium's fertiliser plant in Alberta is currently being retrofitted with a carbon dioxide capture unit. Around 585,000 tonnes per annum of carbon dioxide will be captured and transported via the Alberta Carbon Trunk Line (ACTL) for enhanced oil recovery.
Execute	**Alberta Carbon Trunk Line ("ACTL") with North West Sturgeon Refinery CO2 Stream**	Up to 1.2 million tonnes per annum of carbon dioxide will be captured at this new heavy oil upgrader in Alberta. In partnership with Enhance Energy, the carbon dioxide will be transported via the Alberta Carbon Trunk Line (ACTL) for enhanced oil recovery.
Execute	**Boundary Dam Integrated Carbon Capture and Sequestration Demonstration Project**	SaskPower is currently retrofitting a coal-based power generator with carbon capture technology near Estevan, Saskatchewan. When fully operational in 2014, this project will capture around 1 million tonnes per annum of carbon dioxide.
Execute	**Gorgon Carbon Dioxide Injection Project**	This component of a larger gas production and LNG processing project will inject 3.4 to 4.1 million tonnes of carbon dioxide per annum into a deep geologic formation. Construction is under way after a final investment decision was made in September 2009.
Execute	**Illinois Industrial Carbon Capture and Storage Project**	The project will capture around 1 million tonnes per annum of carbon dioxide from ethanol production. Carbon dioxide will be stored approximately 2.1 km underground in the Mount Simon Sandstone, a deep saline formation.
Execute	**Kemper County IGCC Project**	Mississippi Power (Southern Company) is constructing an air-blown 582 Mwe IGCC plant using a coal-based transport gasifier. Up to 3.5 million tonnes per annum of carbon dioxide will be captured at the plant and used for enhanced oil recovery.
Execute	**Lost Cabin Gas Plant**	This project will retrofit the Lost Cabin natural gas processing plant in Wyoming with CCS facilities, capturing around 1 million tonnes per annum of carbon dioxide to be used for enhanced oil recovery.
Execute	**Quest**	Quest will capture up to 1.2 million tonnes of carbon dioxide per annum from the Scotford upgrader, and transport it by pipeline for injection into a deep saline formation.
Define	**Coffeyville Gasification Plant**	CVR Energy is developing a new compression facility at its fertiliser plant in Kansas. The plant currently produces approximately 850,000 tonnes of carbon dioxide which will be transported to the mid-continental region for use in enhanced oil recovery.

State / District	Country	Volume CO_2	Operation Date	Facility Details	Capture Type	Transport Length	Transport Type	Storage Type	Project URL
Texas	UNITED STATES	8.4 Mtpa	2010	Natural Gas Processing	Pre-Combustion (Gas Processing)	256 km	Onshore to on-shore pipeline	Enhanced Oil Recovery	http://www.oxy.com/
Oklahoma	UNITED STATES	0.68 Mtpa	1982	Fertiliser Production	Pre-Combustion	225 km	Onshore to on-shore pipeline	Enhanced Oil Recovery	http://www.kochfertilizer.com/
Saskatchewan	CANADA	3 Mtpa	2000	Synthetic Natural Gas	Pre-Combustion	315 km	Onshore to on-shore pipeline	Enhanced Oil Recovery	http://www.cenovus.com/
Wilaya de Ouargla	ALGERIA	1 Mtpa	2004	Natural Gas Processing	Pre-Combustion (Gas Processing)	14 km	Onshore to on-shore pipeline	Onshore Deep Saline Formations	http://www.insalahco2.com/
Wyoming	UNITED STATES	7 Mtpa	1986	Natural Gas Processing	Pre-Combustion (Gas Processing)	190 km	Onshore to on-shore pipeline	Enhanced Oil Recovery	http://www.exxonmobil.com
North Sea	NORWAY	1 Mtpa	1996	Natural Gas Processing	Pre-Combustion (Gas Processing)	0 km	Direct injection	Offshore Deep Saline Formations	http://www.statoil.com/en/
Barents Sea	NORWAY	0.7 Mtpa	2008	Natural Gas Processing	Pre-Combustion (Gas Processing)	152 km	Onshore to offshore pipeline	Offshore Deep Saline Formations	http://www.statoil.com/en/
Texas	UNITED STATES	1.3 Mtpa	1972	Natural Gas Processing	Pre-Combustion (Gas Processing)	132 km	Onshore to on-shore pipeline	Enhanced Oil Recovery	http://www.exxonmobil.com/
Texas	UNITED STATES	1 Mtpa	2013	Hydrogen Production	Post-Combustion	101 – 150 km	Onshore to on-shore pipeline	Enhanced Oil Recovery	http://www.airproducts.com/
Alberta	CANADA	Up to 0.59 Mtpa (initially 0.29 Mtpa)	2014	Fertiliser Production	Pre-Combustion	240 km	Onshore to on-shore pipeline	Enhanced Oil Recovery	http://www.agrium.com/
Alberta	CANADA	1.2 Mtpa	2015	Oil Refining	Pre-Combustion	240 km	Onshore to on-shore pipeline	Enhanced Oil Recovery	http://www.northwestupgrading.com/
Saskatchewan	CANADA	1 Mtpa	2014	Power Generation	Post-Combustion	100 km	Onshore to on-shore pipeline	Enhanced Oil Recovery	http://www.saskpower.com/
Western Australia	AUSTRALIA	3.4 - 4.1Mtpa	2015	Natural Gas Processing	Pre-Combustion (Gas Processing)	7 km	Onshore to on-shore pipeline	Onshore Deep Saline Formations	http://www.chevronaustralia.com/
Illinois	UNITED STATES	1 Mtpa	2013	Chemical Production	Industrial Separation	1.6 km	Onshore to on-shore pipeline	Onshore Deep Saline Formations	http://www.adm.com/
Mississippi	UNITED STATES	3.5 Mtpa	2014	Power Generation	Pre-Combustion	75 km	Onshore to on-shore pipeline	Enhanced Oil Recovery	http://www.mississippipower.com/
Wyoming	UNITED STATES	1 Mtpa	2013	Natural Gas Processing	Pre-Combustion (Gas Processing)	Not specified	Onshore to on-shore pipeline	Enhanced Oil Recovery	http://www.conocophillips.com/
Alberta	CANADA	1.08 Mtpa	2015	Hydrogen Production	Pre-Combustion	84 km	Onshore to on-shore pipeline	Onshore Deep Saline Formations	http://www.shell.ca/
Kansas	UNITED STATES	0.85 Mtpa	2013	Fertiliser Production	Pre-Combustion	112 km	Onshore to on-shore pipeline	Enhanced Oil Recovery	http://www.cvrenergy.com/



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Net electric power
180 MWe

Pure water
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