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Front cover: Toshiba's 10t-CO2/day pilot plant at the Mikawa Power Plant, Omuta City, Fukuoka, Japan

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Toshiba's pilot programme results

Toshiba has achieved 2.6GJ/ tonne-CO2 at its 10tonne-CO2/day pilot plant using the flue gas from the Mikawe coal fired power plant.

By Yukio Ohashi, Takashi Ogawa and Kensuke Suzuki, Toshiba Corporation

Most CCS systems provide a large penalty to the performances of thermal power plants because of the vast energy taken from the steam for the power generation. They also require a huge investment and operational costs. Therefore, more economical systems are strongly demanded. In early 2011 Toshiba had proven a least energy consumption of 2.6GJ/t-CO2 or less at our 10t/day pilot plant.

Toshiba has been supplying many efficient steam turbine cycles for thermal and nuclear power plants all over the world. Since 2007 we have also been concentrating on the development of a post-combustion CO2 capture system for helping to solve the global environmental problem[1],[2].

We are pushing through the post-combustion carbon dioxide capture because it can be employed in rather a short period aof time nd can be applied for both retrofit and new power plants. Toshiba will be able to supply low cost CCS installed thermal power plants by integrating power generation, flue gas treatment and CCS system.

Design and construction of the pilot plant

We had started the design and engineering of a 10t-CO2/day pilot plant in 2008, and in September 2009 completed it according to the schedule of Table 1, which works on the flue gas from the Mikawa coal fired thermal power plant located in Fukuoka, Japan, which is owned by Sigma Power Ariake Co.,Ltd. a subsidiary of Toshiba. The specification of the pilot plant is shown in Table 2.

The appearance is shown in Fig.1. As shown in Fig.2 the flue gas of the power plant is introduced downstream of the existing FGD and supplied to the absorber via the additional FGD which removes most of the SO2 in the flue gas. At the outlet of the stripper the steam contained in the produced gas is removed by the condenser and almost pure CO2 gas can be obtained.

Demonstration tests of the pilot plant

Now it has been operating continuously using the flue gas from the coal-fired power plant and the cumulative operating time has reached 4,308 hours as shown in Fig 3. During this period, stable operations and a better CO2 capture performance than planned has been maintained.

We have also developed a novel amine solvent called TS-1 (Toshiba Solvent 1) by our R&D activities since 2007 which will be described later. By using this TS-1, CO2 capture ratio and captured CO2 rate exceeded the planning values of 90 % and 10t-CO2/day respectively during continuous 3,000 hour operation as shown in Fig.4. Fluctuations of these values in Fig.4 are due to those of the CO2 concentration of the flue gas from the Mikawa power plant at the absorber inlet. Furthermore the energy consumption for CO2 recovery at the reboiler had been kept between 3.2 and 3.3 GJ/t-CO2 at a CO2 capture ratio of around 90% as shown in Fig.5 [3].

On the other hand the concentrations of degraded substances, such as carbonic acid, had been increasing within the TS-1 solvent. But as shown in Fig.6 the increasing rate is much lower than other solvents, such as MEA during 3,000 hours of operation [4].

These results prove that Toshiba's CO2 capture system using the TS-1 solvent is a promising system which has been realizing good performance and not degrading during its continuous operations under actual live flue gas.

Figure 1 - the 10t-CO2/day pilot plant at Sigma Power Ariake Co., Ltd. Mikawa Power Plant, Omuta City, Fukuoka, Japan

2008	11	Engineering & Permits
	12	
2009	1	
	2	
	3	Material Procurement, Manufacturing & Construction
	4	
	5	
	6	
	7	
	8	Commissioning
	9	Test Period-1
	10	
	11	
	12	Alteration
2010	1	Test Period-2
	2	
	3	Alteration
	4	Test Period-3
	5	
	6	
	7	
	8	Alteration
	9	
	10	Test Period-4
	11	Alteration
	12	
2011	1	Test Period-5
	2	
	3	

Table 1 - procedure of the pilot plant tests

Location	Mikawa Thermal Power Plant SIGMA POWER Ariake
Source Gas	Flue Gas of Coal-Fired Boiler
Treated Gas Flow Rate	2100Nm^3/h
CO_2 Concentration	Approx. 12%
CO_2 Capture Ratio	90%
Captured CO_2	10t-CO_2/day
Impurities	SOx, NOx, Dust, etc
Solvent	TS-1 Solvent

Table 2 - pilot plant specifications

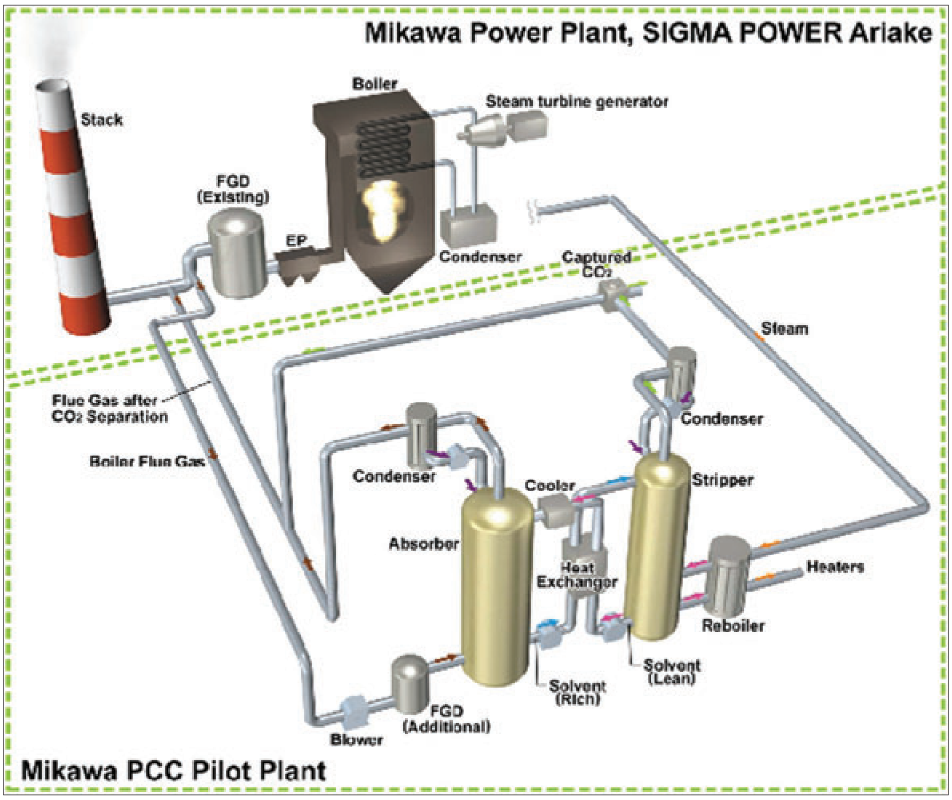

Figure 2 - schematic diagram of the pilot plant with the Mikawa Power Plant

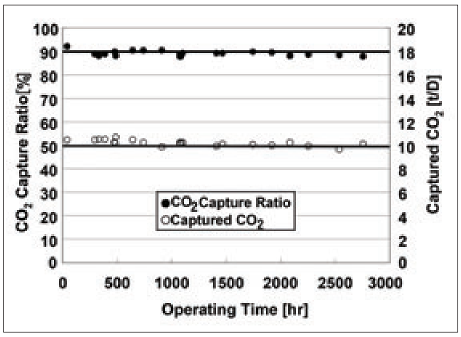

Figure 4 - performance of the pilot plant

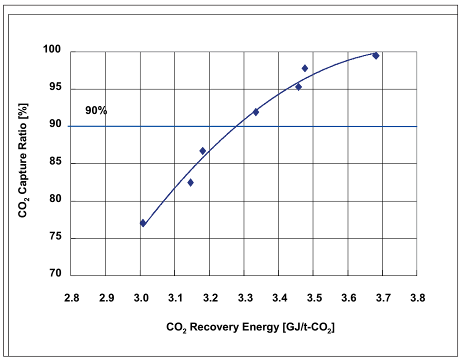

Figure 5 - CO2 capture ratio vs. CO2 recovery energy

Improvement of the pilot plant and evaluation tests

Based on the analysis of these test results, we had found an improved system structure of the pilot plant to reduce the consumed energy in the through thermodynamic system simulation. Then we had redesigned and reconstructed the pilot plant. As shown in Fig.7, the latest test results showed the least energy of 2.6 GJ/t-CO2, far less than 3.0 GJ/t-CO2, with exceeded values of 90% CO2 capture ratio and 10t-CO2/day captured CO2 rate by using our developed solvent TS-1.

According to the heat loss tests and analysis, it is expected that the consumed energy would be reduced by 0.3 GJ/t-CO2 by reinforcing the thermal insulation at the pilot plant, which means that the value of 2.3 GJ/t-CO2 would be possible at larger scale commercial plants [4].

It is the first time in the world that the consumed energy of much lower than 2.8-3.0 GJ/t-CO2 has been proved at a 10t-CO2/day scale pilot plant using the actual flue gas of the coal fired power plant, not only by simulations.

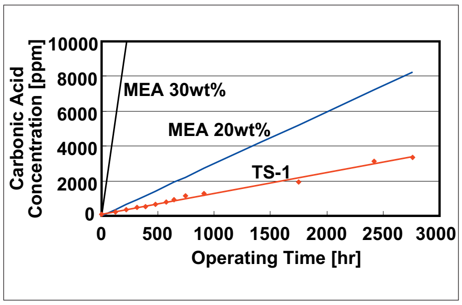

Figure 6 - degradation rate of TS-1 solvent

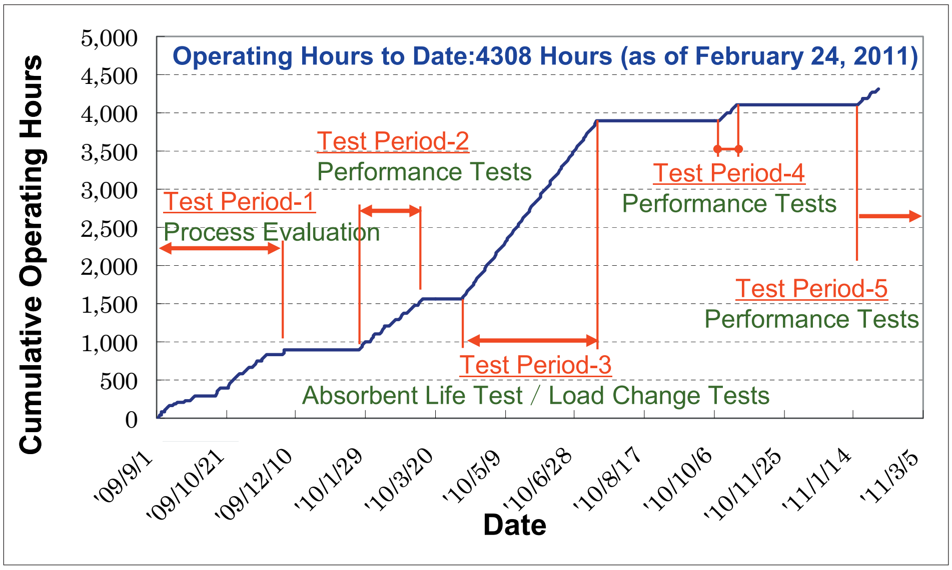

Figure 3 - test schedule and cumulative operating time

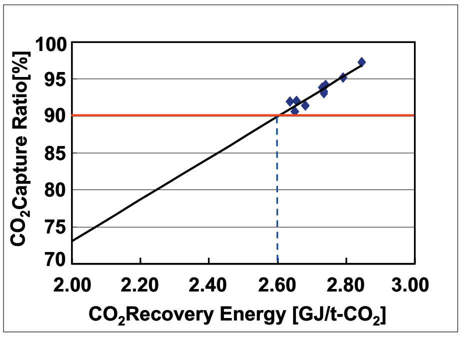

Figure 7 - improved CO2 recovery energy

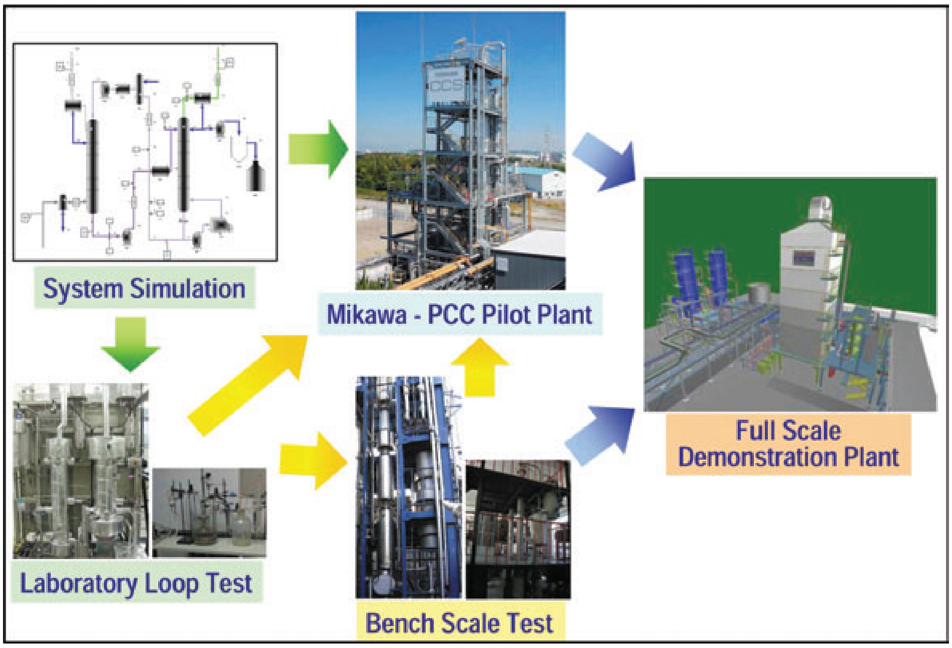

Figure 8 - scope of R&D activities

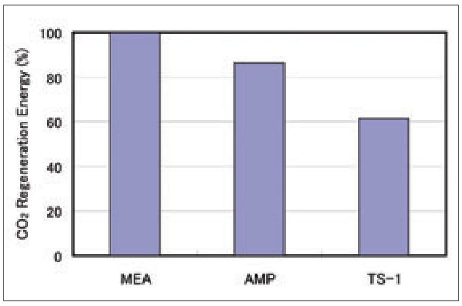

Figure 10 - comparison of CO2 regeneration energies by thermodynamic simulations

Fundamental research & development

The scope of our R&D activities is shown in Fig.8. In order to screen the solvents, the thermodynamic system simulations and the measurement of the fundamental properties of solvents have been carried out. Then the bench-scale test and thermodynamic system simulation to decide the operating condition have been done for the promising candidate solvent. Finally we have designed the pilot plant using these results. For the future, we have been designing the full scale demonstration plant using the results of verification test sat the pilot plant.

(1) Screening of solvents by thermodynamic simulation

In order to search for promising solvents, we carried out the thermodynamic simulations at the CO2 absorption and desorption cycle shown in Fig.9 which includes an absorber, a stripper, and a lean/rich solvent heat exchanger. We estimated the consumed energy at the stripper under the conditions that the CO2 concentration of the flue gas is 12 % and the CO2 capture ratio from the flue gas is 90 %.

Figure 10 shows the results of thermodynamic system simulation on the lowest heats consumed in the stripper for three amine solutions. The lowest heat consumed in the stripper for the general 30 weight% mono-ethanolamine (MEA) aqueous solution is 4.4GJ/t-CO2, which is nearly equal to the literature value [5]. The value for the

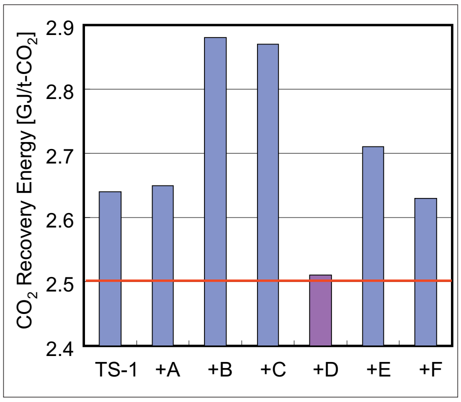

Figure 11 - screening of candidate solvents by CO2 recovery energy

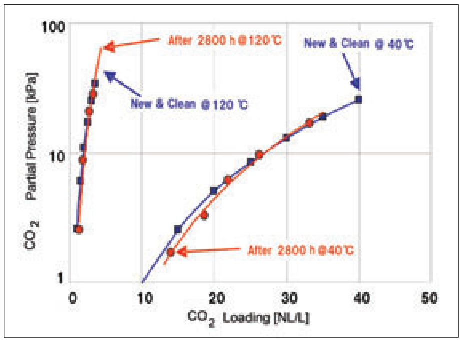

Figure 12 - vapor liquid equilibrium curves before and after operations

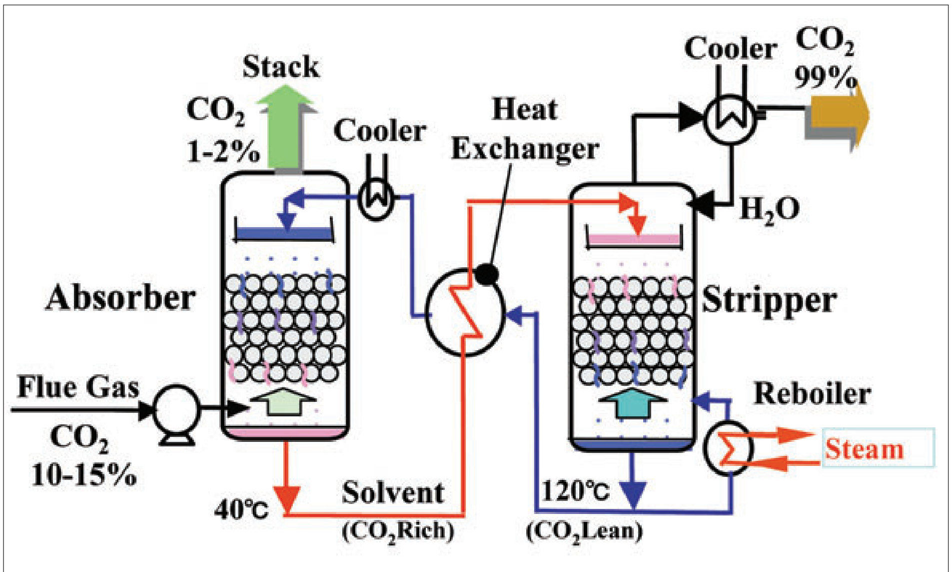

Figure 9 - system configuration for thermodynamic simulations

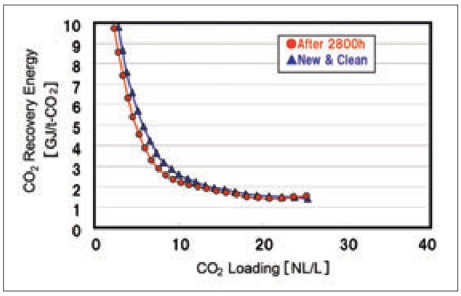

Figure 13 - CO2 recovery energy curves before and after operations

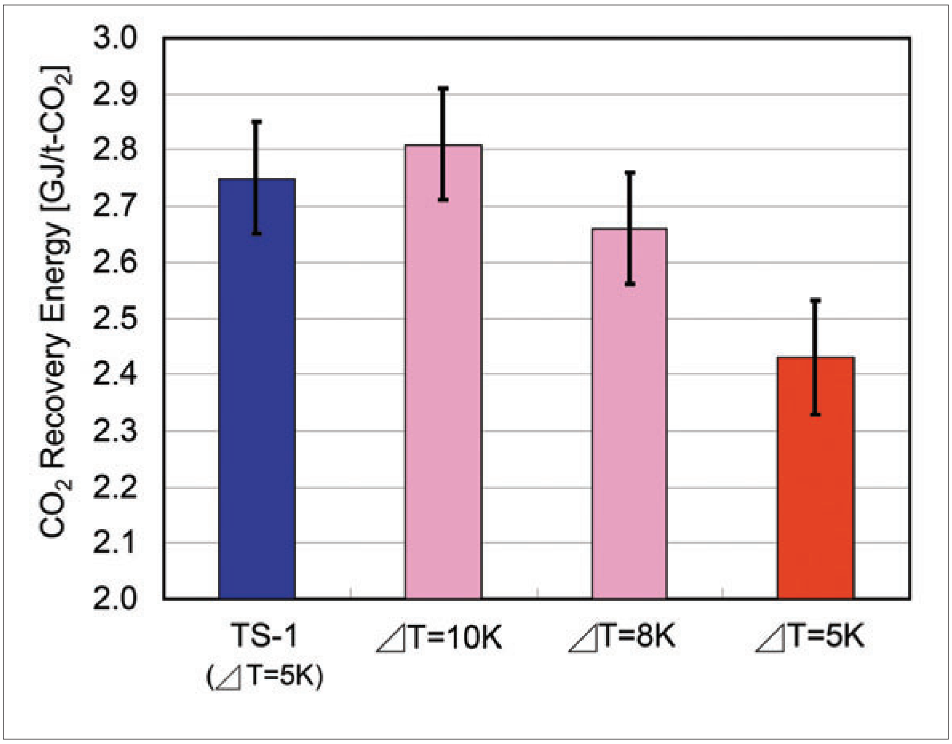

Figure 14 - test results of bench scale test facility

aqueous 2-amino-2-methyl-l-propanol (AMP) solution is about 15% less than that of MEA solution. Furthermore, the value for TS-1 is about 37% less than that of MEA solution.

Then seven candidate solvents which are mixtures of TS-1 and an amine-based absorbent were evaluated. As shown in Fig.11 it was found that TS-1 mixed with an absorbent D (Toshiba Solvent 2, TS-2) was the lowest consumed heat in the stripper and its value became about 2.5 GJ/t-CO2. Besides two mixed solvents showed about 2.6 GJ/t-CO2.and other mixed solvents about 2.7 and 2.9 GJ/t-CO2 each

(2) Laboratory-scale tests

We have two laboratory loops shown in Fig.8 in order to measure fundamental properties of various kinds of solvent. They are not only liquid properties, such as the density, heat capacity, viscosity, but also VLE(Vapor Liquid Equilibrium), stripping energy of CO2 and mass transfer coefficient. These measured values are used at the screening of the solvents by the thermodynamic system simulations, and at the evaluations of the degradation effects to solvent's erformances.

Furthermore we evaluate the performance degradations of the solvent comparing the used solvent with new one. In Fig.12 the VLEs are compared, while in Fig.13 the CO2 recovery energies. The degradation effects by SOx and NOx to the solvent performances were also investigated using these loops and the bench-scale test loop.

(3) Evaluation of promising solvents by bench-scale test facility

As the next step of the screening by the thermodynamic system simulations, evaluations using the bench-scale test facility shown in Fig.8 were performed. The test facility realizes a complete absorption/desorption process which has the absorber with the diameter of 160 mm and the height of 6,000 mm, and the stripper with the diameter of 200 mm and the height of 3,600 mm. A flue gas of coal-fired power plant was simulated by a mixture of air and CO2 whose concentration is 12%. We optimized the space velocity of the simulated flue gas and the weight ratio of the solvent to the simulated flue gas in the absorber.

In Fig.14, TS-1 showed the lowest energy consumed in the stripper was about 2.7 GJ/t-CO2 with 90 % CO2 removal, which was nearly equal to the value, about 2.6 GJ/t-CO2, predicted at the thermodynamic system simulation. While absorbent D (TS-2) showed lower consumed energy of less than 2.5 GJ/t-CO2 when the minimum temperature difference between the hot CO2 rich solvent which entered the stripper and the CO2 lean solvent entered the lean/rich heat exchanger is 5 K. This condition, 5 K, is same as that of TS-1 and is achievable at the 10 t-CO2/day pilot plant to be described in the next chapter. The consumed energy in the stripper depended strongly on the temperature difference. The effect by the increased temperature differences from 5 K to 10 K is shown in Fig.14 [3].

For the future CCS system of Toshiba

We have been continuing to search and screen the new candidates of the solvent including the derivatives containing the amino group in order to reduce the energy consumption and to enhance the durability and reliability.

From the recent concern about the environmental effects by the amine solvent, the prevention of the emissions from the top of the absorber and stripper is strongly required. Therefore we are planning to install a test apparatus at our pilot plant this year to evaluate the quantities of the emitted amines and to find effective measures.

One of Toshiba's great advantages is to have the pilot plant using the flue gas from a working coal fired power plant. Based on the fundamental R&D activities, we can verify the improved performance and the environmental effects to realize a future commercial plant integrated with power generation.

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Air Liquide's new pilot carbon capture unit at CIUDEN plant

Air Liquide has been selected to supply the CO2 cryogenic purification unit for CIUDEN's pilot plant in Northwest Spain.

By Fred Lockwood, Industrialisation Manager - CO2 Capture Technologies and Nicolas Perrin, Director, Clean Power & CCS, Air Liquide

Concern for environmental problems lies at the heart of Air Liquide's corporate strategy. Air Liquide is participating in the development of Carbon Capture and Storage, particularly through its expertise in oxycombustion and gas treatment. Using these techniques, large quantities of CO2 emissions from industrial plants can be concentrated, purified and stored underground, which avoids large-scale discharge into the atmosphere.

Air Liquide has recently signed a contract to provide the CPU (CO2 Cryogenic Purification Unit) technology for CIUDEN's Integrated CCS Technology Development Plant (TDP) located near Endesa's Compostilla power plant (Spain). This pilot forms an important part of Air Liquide's CPU technology development for oxycombustion power plants. This article summarises Air Liquide's vision for the pilot plant and its place in the roadmap for CPU systems.

Oxycombustion power plants produce flue gases that are at low pressure and that are rich in carbon dioxide. They require units for purifying and compressing the flue gases to produce pure carbon dioxide that can be transported by pipeline or ships to a suitable storage location. Air Liquide is following a comprehensive roadmap (see illustration above) in order to develop this technology CRYOCAP™ OXY for commercial plants.

Following an initial period of lab-scale tests and engineering studies, Air Liquide's CPU development effort entered a phase focused on pilot plants. In 2008, Air Liquide signed a contract to supply the CPU unit for the Callide Oxyfuel project. The objective of this pilot is to test a 'first generation' of CPU technologies that could be up-scaled to industrial size. Examples of technologies to be tested are advanced dust filtration systems and centrifugal compressors for flue gas compression. Furthermore, since 2010, Air Liquide has also been testing flue gas drying systems developed specifically for oxycombustion on Total's CCS project at the Lacq site in France.

Air Liquide identified the CIUDEN pilot as a significant opportunity. Of particular importance is the flexibility offered by the technology development plant due to the possibility to run either a Circulating Fluidized Bed (CFB) boiler (30MWth) or a Pulverised Coal (PC) boiler (20MWth) with a range of coal types. Furthermore, CIUDEN's technology development plant offers the

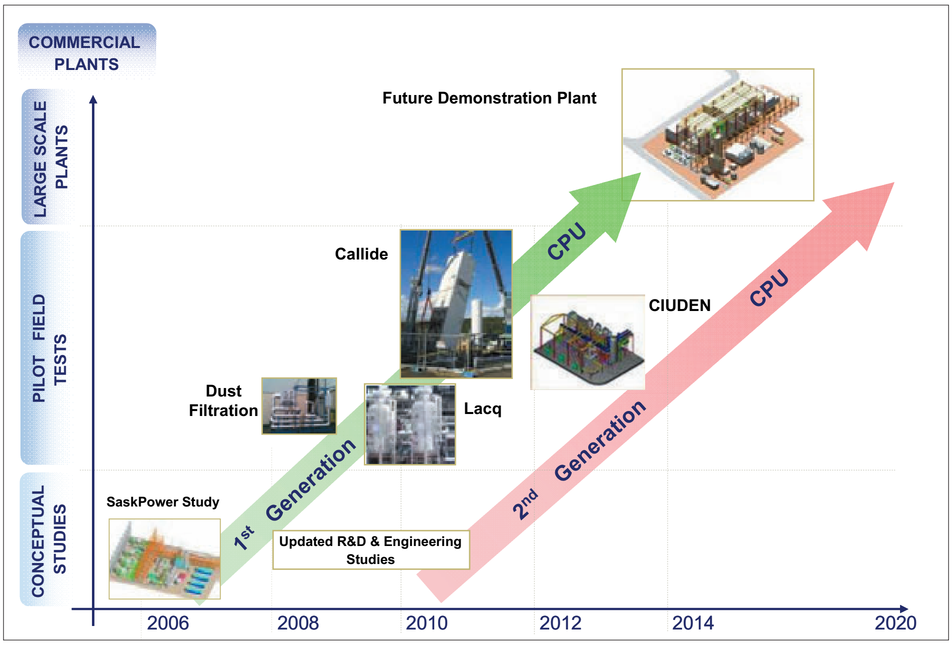


Illustration - Air Liquide's roadmap for oxycombustion CPU CRYOCAT™ OXY development

CIUDEN's Test Development Plant near Ponferrada in Northwest Spain

possibility to use different flue gas treatment systems. For example, the installed selective catalytic reduction (SCR) unit for nitrous oxide removal may be by-passed if required.

Air Liquide decided to develop a CPU test platform at CIUDEN for the long-term, building on the design of the Callide pilot. The objective is to test advanced 'second generation' technologies in addition to further testing key 'first generation' systems. Examples of technology fields to be studied are: acid gas washing, advanced dust filtration and advanced flue gas drying and compression. Start-up of the pilot is planned for the first half of 2012.

Acid gas washing is an important technology since it enables species that may form strong acids in presence of liquid water such as sulphur oxides and hydrogen fluoride to be removed from the flue gas. This mitigates the risk of corrosion in the CPU. A part of the CIUDEN pilot will be dedicated to the study of these systems.

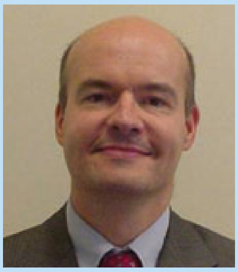
Advanced Dust filtration Technology is used in Air Liquide's CPU design in order to mitigate the risk of fouling and abrasion in the CPU. The CIUDEN CPU will be a unique opportunity to test these systems. This opens the possibility for clients developing oxycombustion demonstration plants to set-up specific test campaigns with coals and flue gas treatment reproducing the flue gas conditions of their future projects.

The CPU design uses a cryogenic process in order to separate carbon dioxide from more volatile compounds such as nitrogen and oxygen. Therefore, it is important to remove water upstream in order to avoid freezing. At CIUDEN, Air Liquide will be testing an advanced water removal system building on work already completed at the pilot in Lacq, France.

In summary, the CIUDEN CPU pilot will play a key role in Air Liquide's CPU technology roadmap, testing a range of important technologies on a wide spectrum of oxy-flue gas conditions. Together with the pilot plants at Callide and Lacq it will provide a firm foundation for the design and construction of the first industrial scale demonstration units.

About the authors

Nicolas Perrin is presently Director of Clean Power & CCS at Air Liquide in charge of coordinating the Group's offer and strategy to these markets.



Nicolas graduated from School of Mines in Paris and moved in various positions within the Air Liquide Group since 1989 including in R&D, business development, operations control, marketing and strategy through international positions in France, South East Asia and in the US.

Nicolas has been in charge of the development of oxycombustion solutions for various industries at Air Liquide since the early 90's. This includes the applications of oxygen in iron and steelmaking, metals, glass, cement and power production. From R&D project management Nicolas evolved over the years to R&D Programs and Marketing / Strategy Direction.

Nicolas has coauthored over 45 presentations and papers at international conferences and publications. He is also co-inventor of over 10 patents in the field of oxycombustion and active member of the European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP).

Fred Lockwood is Industrialisation Manager - CO2 Capture Technologies. He has been working in the field of CO2 capture since 2004 when he joined Air Liquide as a CO2 capture engineer.

Previously he worked for Renault while studying for his MBA.

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CCS legal and policy – Nov / Dec 2011

The deadline for EU member states to transpose the EU Directive on the Storage of Carbon Dioxide passed on the 25 June this year. The degree of compliance with this deadline, the transposition methods employed and the extent of acceptance of the new law in various member states are important indicators of how CCS is likely to develop across Europe.

EU Directives are pieces of European legislation that set out results to be achieved rather than specific rules. It is for each Member State to decide how the results required by the Directive should best be obtained within its territory and to pass national laws to do this. This process is known as transposition and the methodological latitude provided for by the purposive nature of Directives means that the national laws which transpose their intentions can vary significantly from state to state.

A Directive must be transposed by a date specified within its text (normally around two years after the Directive comes into force) and the transposition must be in conformity with the requirements of the Directive. Failure to transpose a Directive in a conforming manner within the specified deadline is an infringement of EU law for which the European Commission can, if its preliminary attempts to resolve the issue fail, bring infringement proceedings before the European courts. The courts may, in turn, apply various penalties and fines on the infringing Member State. Infringement proceedings are not unusual (there were over 450 open infringement proceedings in 2009 in the area of environmental law alone) and the vast majority are settled without reference to the courts; nevertheless, the threat of court sanctions exist.

With regard to the Directive on the Storage of Carbon Dioxide (the 'Directive'), the UK has not completed its transposition and is not alone. Of the 27 EU member states only two, Spain and Romania, claim to have transposed the Directive completely and it is yet to be seen whether their efforts are considered satisfactory by the Commission. 15 member states have not communicated any transposition at all to the Commission and the

remaining ten (including the UK) have communicated only partial transposition. Accordingly, infringement procedures related to failure to transpose the Directive were launched by the Commission on 18 July against 25 out of the 27 European member states. This is less than encouraging.

One possible contributing factor to the UK having yet to completely transpose the Directive is that it has chosen to carry out the task in a piecemeal fashion rather than by producing a single piece of legislation that transposes the entire Directive in one fell swoop. The Carbon Dioxide (Access to Infrastructure) Regulations (the 'TPA Regs'), for example, transposes only the third party access requirements included in Chapter 5 of the Directive.

In addition, wherever possible, the UK's transposing instruments replicate or amend existing legislative frameworks or provisions; again, by way of example, the TPA Regs are closely based upon the existing, and well tried and tested, regulatory framework covering third party access to offshore oil and gas infrastructure. As a result of this transposition methodology there are now, in addition to the CCS related provisions included in the Energy Act 2008, a number of 'Storage of Carbon Dioxide Regulations' either in force or moving through the legislative process.

Progress in Europe

It is interesting to compare how things have progressed in other European states, especially those that are host to attempts to develop CCS. In Germany, a single Bill to transpose the entire Directive was laid before parliament in April 2009 but, against a backdrop of significant public protest, the Bundestag, Germany's first chamber, failed to reach agreement upon it and it lapsed. In April this year a second Bill was put before Parliament and this was rejected by the Bundesrat, the second chamber, in September.

The Bill is not yet dead as there remains a Conciliation Committee route via which it may still make law, but this may be a moot point since RWE has discontinued the Hürth project and Vattenfall has declared itself 'pessimistic' with regard to the future of its Jänschwalde project. Both companies have cited the progress of German CCS law and policy as major factors affecting their decisions.

Spain, like Germany, chose to transpose the Directive by means of a single new piece of legislation and accordingly 'Ley' 40/2010 passed into Spanish law in December 2010. The legislation largely replicates the provisions of the Directive and secondary legislation is required to make the provisions operational and specify detail; on the transposition deadline date in June this had not yet been published. Spain is also similar to Germany in that its regions have a good deal of autonomy and political strength and that it is only considering onshore storage sites for CCS purposes.

Although this has not led to the large public outcry in Spain that it has in Germany, Ley 40/2010 is the subject of a challenge in the Spanish Constitutional Court on the basis that it may not reflect the correct division of competencies between Spanish central and regional governments. Unlike the German case, this hiccup in the legal process is not seen as a threat to eventual passage of the law per se. Nevertheless, following Endesa's decision to suspend the Compostilla project, CCS law in Spain may also be left with nothing to govern in the short to medium term.

When considering Directive transposition methods, Romania is also an interesting case. The Directive was transposed into Romanian law by Government Emergency Ordinance (GEO) 64/2011. However, the GEO is a more or less verbatim version of the text of the Directive and in practice additional secondary (and possibly primary) legislation will have to be passed before there is any practically applicable CCS law in Romania.

How this tactic is received by the European Commission when it considers whether the purported transposition of the Directive into Romanian law is in conformity with its requirements will be instructive for other member states considering how to deal with infringement proceedings at the lowest cost and inconvenience.

Conforming to the rules

Conformity checking of those transposition measures that have been put in place by member states is, I believe, currently underway or shortly to start. One area which might attract scrutiny from the Commission is that of the provisions in the UK TPA Regs which prevent the access by third parties to storage capacity which may be physically available but which is over-and-above that which has been applied for and authorised in a sites' storage permit.

The genuine concerns of potential storage site operators with respect to the limited accuracy with which storage reservoir capacities can be ascertained prior to injection are valid and a requirement to provide access to capacity in excess of that which can be reasonably proved to be available would clearly not be desirable. On the other hand, regulation that gives a storage operator the ability, via the permitting system, to restrict the effective capacity of its storage site to a level that is below that which could safely be made available in order to restrict the capacity of an overall CCS system to that which meets the needs of a restricted number of emitters would appear to be wholly contrary to the requirements of the Directive that fair and open access to CCS infrastructure should be made available to third parties on a non-discriminatory basis. It is not untenable to argue that the TPA Regs should be construed as non-conforming in this regard.

Calum Hughes, Yellow Wood Energy

Even without the risk of infringement proceedings, acceptable transposition of the Directive is potentially important for all those member states that are hosting bids for CCS project funding from the NER300 fund. The Commission decision which sets out the criteria governing the NER300 financing process requires that funding awards are conditional upon 'all relevant permits in accordance with relevant requirements under Union law being issued' within 24 months of the decision (36 months where storage is in a saline aquifer).

The term 'relevant permits' is not further defined but it seems clear that a project sited in a member state that was not in a position to issue such permits by the stated deadline because the necessary legal framework had not been enacted in a timely manner would risk losing any funding it had been granted. Whether a significant possibility of such a situation occurring should constitute grounds for the EC / EIB to refuse funding in the first place is a matter of opinion.

Project developers are often justifiably critical of the length of time it takes for the legal and regulatory frameworks which affect their projects to be developed and the risks and additional costs this introduces. Despite a great deal of progress and the timely enactment of the Directive it appears that CCS legislation across Europe is becoming susceptible to this criticism. Considering the above may shed light on some of the reasons why and emphasise there is still a long way to go.

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GCCSI Global Status of CCS 2011 update

The annual GCCSI report highlights 'measured' progress in 2011 with an increase in the number of large-scale integrated projects (LSIPs) in operation or under construction and a clustering of projects around the advanced stages of development planning.

There are eight large-scale projects in operation around the world and a further six under construction, according to the GCCSI's report, 'The Global Status of CCS: 2011'. Three of these projects have recently commenced construction.

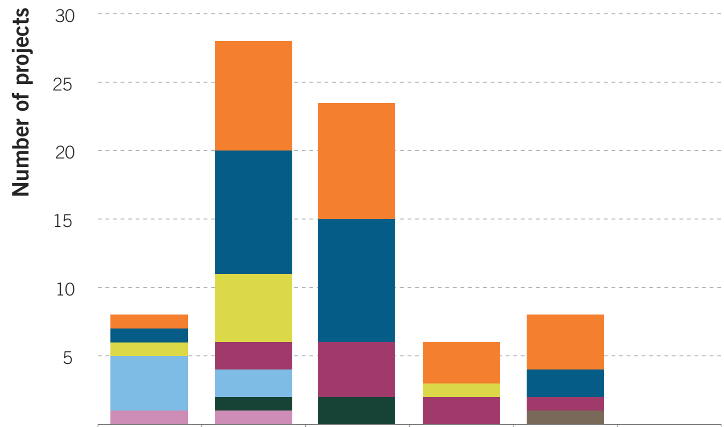
Importantly, these include a second power project, Boundary Dam in Canada, in addition to Kemper County in the United States. The United States also has its first project under construction that will store CO2 in a deep saline formation - the Illinois Industrial Carbon Capture and Sequestration (ICCS) project.

The total CO2 storage capacity of all 14 projects in operation or under construction is over 33 million tonnes a year. This is broadly equivalent to preventing the emissions from more than six million cars from entering the atmosphere each year.

In the Institute's annual project survey for 2010, ten projects reported that they could be in a position in the next 12 months to decide on whether to take a final investment decision (FID) and move into construction. Power generation projects are prominent in this group and include Project Pioneer in Canada, the Texas Clean Energy project in the United States and the ROAD project in Europe.

While the prospect of a number of power projects moving to a FID in the next year is a positive development, this is contrasted with other high-emitting industries such as iron and steel and cement, where there is a paucity of projects being planned at large-scale.

In total there are 74 LSIPs recorded in the report, compared with 77 reported in the Global Status of CCS: 2010 report. These CCS projects continue to be concentrated in North America, Europe, Australia and China with few large-scale projects planned in developing countries.



	Identify	Evaluate	Define	Execute	Operate	Total
United States	1	8	9	3	4	**25**
Europe	1	9	9	0	2	**21**
Australia and New Zealand	1	5	0	1	0	**7**
Canada	0	2	4	2	1	**9**
China	4	2	0	0	0	**6**
Middle East	0	1	2	0	0	**3**
Other Asia	1	1	0	0	0	**2**
Africa	0	0	0	0	1	**1**
Total	**8**	**28**	**24**	**6**	**8**	**74**

Large scale integrated projects (LSIPs) by asset lifecycle and region/country (Source:Global Status of CCS 2011 ©GCCSI 2011)

Factors influencing a project's success

As with most industrial projects, building a viable business case for a CCS demonstration project is a complex and time consuming process that requires both the project economics and the risks to be understood prior to a FID.

All projects in operation use CO2 separation technology as part of an already established industry process and either use CO2 to generate revenue through enhanced oil recovery (EOR) and/or have access to lower cost storage sites based on previous resource exploration and existing geologic information sets. Six of the eight operating projects are in natural gas processing, while the other two are in synthetic fuel production and fertiliser production, and five of these projects use EOR.

A number of projects in operation or under construction are undertaking CCS in response to, or anticipation of, longer-term climate policies and/or potential carbon offset markets. While this is promising, developing a business case is challenging especially when projects do not have access to either revenue streams, such as EOR or other opportunities, or where CO2 capture is not already part of an established industrial process.

There are 11 LSIPs that are considered on-hold or cancelled since the Institute's 2010 report, with eight in the United States and three in Europe. The most frequently cited reason for a project being put on-hold or cancelled is that it was deemed uneconomic in its current form and policy environment. The lack of financial support to continue to the next stage of project development, and uncertainty regarding carbon abatement policies and regulations were critical factors that led several project proponents to reprioritise their investments, either within their CCS portfolio or to alternative technologies.

This clearly indicates that substantial, timely and stable policy support, including a carbon price signal, is needed for CCS to be demonstrated and then deployed. This support will give industry confidence to continue moving forward and invest in CCS. In turn, such investment would ensure continuing innovation which will ultimately help to drive down capital and operating costs.

Both government and the private sector have a role in resolving and bringing greater transparency to business case issues so that the demonstration of CCS progresses and associated learnings and benefits are realised.

CCS in the power sector

Power generation projects have significant additional costs and risks from scale-up and the first-of-a-kind nature of incorporating capture technology. Electricity markets do not currently support these costs and risks, even where climate policies and carbon pricing are already enacted. A major cost for CCS is the energy penalty or 'parasitic load' involved in applying the technologies. Going forward a major emphasis in pre-, post- and oxyfuel combustion capture applied to power stations (and other industrial applications) is on research into reducing this cost.

Despite these challenges, construction of a post-combustion capture project (Boundary Dam in Canada) and an integrated gasification combined cycle (IGCC) project (Kemper County) is proceeding. This indicates that the technology risk for these applications is considered manageable and the technical barriers are not insurmountable, if other conditions are right, such as allowance for the added cost into the rate base and other incentives. Both these projects received government support and will be selling CO2 for EOR, thus tapping into another revenue stream. They are also demonstrating some elements of risk mitigation in the project design, by either having a relatively low CO2 capture rate from the flue gas stream (in the case of Kemper County) or capturing CO2 from a relatively small power unit (in the case of Boundary Dam).

It is vital these and other planned demonstration power projects are successful in carrying out CCS on a commercial-scale and operating in an integrated mode, in real electricity wholesale markets and with storage at sufficient scale to provide the confidence and benchmarks critical for future widespread deployment.

Capture, transport and storage issues

The eight operating CCS projects in the natural gas processing, synthetic fuels and fertiliser production industries attest to the proven nature of the capture technology in these applications. As noted above, while there are projects proceeding to construction in the power sector, there is a need for more projects to demonstrate the range of possible capture technologies that could be applied. There have been limited recent developments in iron and steel sector demonstrations of capture technologies. In the cement sector, capture technology is still at an early stage. Both these industries are major emitters and further developments are expected and necessary.

Pipeline transport of CO2 is a proven and well developed technology, but it is the scale of the future CO2 transport requirements that will require strong investment support. While pipelines are expected to be a cost-effective transport solution, with increasing distance and in certain circumstances, shipping can be cost competitive and offers greater flexibility to serve multiple CO2 sources and sinks. Significant economies of scale can result from shared transport infrastructure, but establishing a network is a large investment that can add considerable risks to early mover projects. These risks need to be understood, in particular by governments when providing incentives for demonstration.

The operating projects demonstrate storage of CO2 in both deep saline formations and through EOR, showing that viable storage is achievable. The storage challenge ahead is with increasing injection volumes, gaining site-specific experience and with continuing improvements to the design and methodologies of measurement, monitoring and verification of storage in effective and appropriate regulatory environments.

Information from project proponents indicates that storage assessment and characterisation requires considerable investment and can have long lead times of five to 10 years or more for a greenfield storage site, depending on the existing available geologic information about the site. Policymakers need to factor these lead times into their assessment of a project's progress. Projects that have not yet commenced active storage assessment may have a challenge to achieve operation before 2020.

As with storage, public engagement is situation and site specific and on a local level must address all aspects of the project, including its possible and potential impacts and benefits. Project proponents need to continuously review their public engagement approach to identify and mitigate potential challenges.

Policy and legal developments

Governments should continue to send strong, consistent and sustained policy signals (including incentives, legislation and regulatory frameworks) to support this early stage of transitioning towards commercial deployment. Some project proponents perceive policy uncertainty as a major risk to project development and it is of particular concern when governments articulate policy intent without implementation.

In the past year the development of CCS laws and regulations has continued, with a number of jurisdictions completing framework legislation and commencing implementation of secondary regulations and guidance. Effective regulatory regimes on a national level play a significant role in the development of CCS projects globally. Notwithstanding these efforts, project proponents have identified a number of issues that in some cases have yet to be adequately addressed, including regulation that is incomplete in nature or delayed. A number of proposals, amendments and review exercises have already been put in motion by regulators and policymakers across several jurisdictions to address such issues. Whether or not these activities will sufficiently address projects' concerns will be an important consideration in the forthcoming years.

Many of the countries and regions that have been acknowledged as leaders in the deployment of laws and regulation for CCS have continued in these roles. In the past year, several European Union Member States, Australia, the United States and Canada have all sustained their regulatory momentum and delivered a number of new proposals, laws, regulations and initiatives. The importance of effective regulation has also been recognised by the many countries that are to become the second generation of CCS lawmakers. Korea is one such example. While many of these countries have yet to pass legislation, or complete the design of their regulatory frameworks, it is clear that significant actions are being taken to facilitate their development. This is particularly noticeable in a number of developing countries that are keen to integrate CCS into future climate change mitigation strategies.

Government funding to support large-scale CCS demonstration projects has remained largely unchanged in 2011. In total, approximately US$23.5bn has been made available by governments worldwide. Competitive funding programs designed to measure and fund the 'gap' required to make projects financially viable have been widely adopted by governments internationally. This approach will be taken by the European Union's NER300 program where 13 CCS projects, together with 65 innovative renewable projects, were identified as meeting the criteria to go forward to the next stage with decisions on funding allocation expected in the second half of 2012.

In the near-term, government policy and funding levels will impact strongly on the rate at which demonstration projects progress and their overall viability. For this to be done effectively, ongoing cooperation between government and industry is required to address the complex challenges in establishing early-mover CCS projects. In the long-term, the value of CCS demonstration can only be realised and supported through sustained forward looking climate change policies and carbon-price signals that will underpin the future deployment of CCS.

More information

Download the full report at:
www.globalccsinstite.com

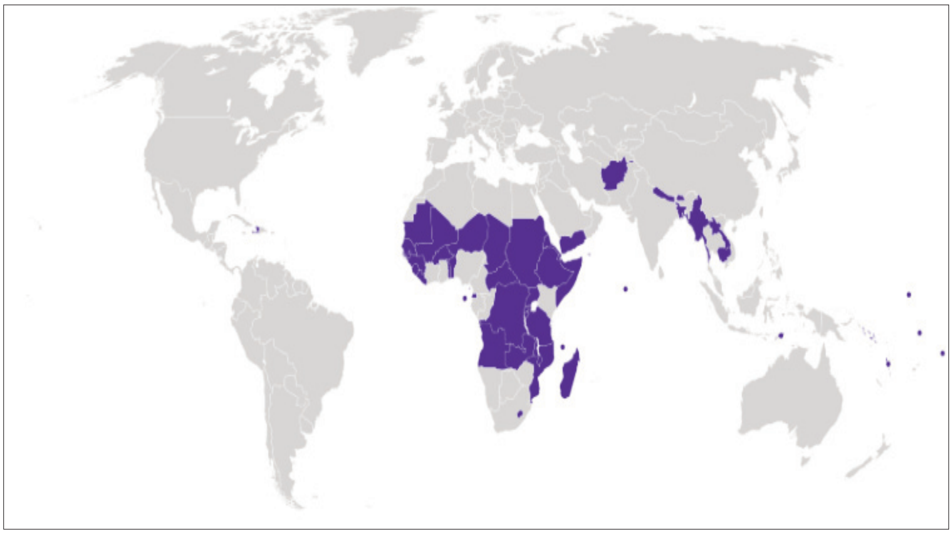
CCS under the CDM – will recent progress be undone by carbon market dynamics?

Just as CCS looks set to be included in the Clean Development Mechanism (CDM), some of the countries with the greatest potential for CDM projects may soon be excluded.

By Lodewijk Nell and Andrew Gilder

After a struggle of many years, a decision was made at the last United Nations Climate Change Conference, COP16 in Cancun, Mexico last year that “carbon dioxide capture and storage in geological formations is eligible as project activities under the Clean Development Mechanism [CDM], provided that the issues identified in decision 2/CMP.5, paragraph 29, are addressed and resolved in a satisfactory manner”.

The Conference requested the Subsidiary Body for Scientific and Technological Advice (SBSTA) to elaborate modalities and procedures in order to enable the inclusion of CCS under the CDM by its 35th session (December 2011) during COP17 in Durban South Africa.



Map of the world showing the Least Developed Countries (LDCs)

Remaining CCS Issues

The issues identified in decision 2/CMP.5 , include permanence of sequestration, long term liability and the risk of leakage. These issues are not new and addressing them should be achieveable in the required timeframe. Consequently SBSTA is likely to devise a workable proposal for dealing with these issues - which will be a positive for CCS activities.

Eligibility under the CDM means that CCS project activities will be entitled to generate Certified Emissions Reductions (CERs) – the carbon credit associated with the CDM – and to take advantage of other CDM benefits such as clean technology transfer.

However, battlelines already drawn elsewhere in the negotiations may negate this progress on CCS and eventually exclude countries like China, India, Ghana, Qatar, United Arab Emirates and South Africa from the CDM altogether. It goes without saying that excluding these countries from the CDM will have the knock-on effect of also removing the lion’s share of developing country CCS from the carbon market.

LDC Exclusivity?

This situation will arise because the European Union (EU) – the largest buyer of CERS in the international market – has indicated that it will purchase CERs exclusively from CDM projects located in Least Developed Countries (LDCs) from 2013.

There is concern among those involved with CDM projects in non-LDCs that this issue is being neglected in the negotiations, as other sources of climate funding, such as the yet to be established Green Climate Fund appear to be gaining favour. While developing countries seek to tap into these “new” sources of funding, there is a dearth of defence of the non-LDC CDM space.

The irony? Now that we are on the verge of seeing CCS included in the CDM, thereby unlocking carbon financial support for the CCS, those non-LDCs with the greatest potential as CCS destinations (whether this potential resides in the country’s advanced state of technical know-how or an abundance of pore space), are soon to be excluded from the CDM arena, altogether, by the largest buyer of carbon credits in the carbon market.

On the 8th of November 2011, the UNFCCC Secretariat has published the draft modalities and procedures:

unfccc.int/resource/docs/2011/sbsta/eng/4.pdf

About the authors

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Bellona report on CCS readiness

A report from Bellona finds that EU CCS requirements were breached by Slovenia

The Bellona Foundation together with Environmental Law Service (ELS) have published a first-of-its-kind report on how CCS feasibility assessments should be carried out: "CCS readiness at Šoštanj: Ticking boxes or preparing for the future?"

It was prepared after a complaint by ELS and the Slovenian NGO Focus to the European Commission about a construction permit for a new 600 MW unit of Šoštanj Thermal Power Plant in Slovenia. According to the complaint, Slovenian authorities failed to meet the requirements of article 33 of the so-called CCS Directive 2009/31/EC that the planned power plant unit be permitted only after the feasibility of a CCS retrofit has been assessed.

The joint Bellona and ELS report suggests how article 33.1 – requiring the feasibility of CCS retrofit to be assessed – should be interpreted in a meaningful way. It then applies this methodology to the Šoštanj case through a detailed analysis of the documents submitted by the project sponsors as evidence that it was "CCS ready". The report reveals that these documents submitted by the operator do not exhaust what can reasonably be expected under article 33.1 of the CCS Directive, as they lack a number of project-specific assumptions and data concerning economic feasibility of the capture, transport and storage. Furthermore, there is a lack of consideration of local geographical conditions' impact on technical feasibility, in particular for building pipelines, etc.

The outcomes of The Bellona Foundation and Environmental Law Service's report show that there is a clear contradiction between the statements made by the European Investment Bank, the European Bank for Reconstruction and Development, which have pledged financial support for the project and the operator's claim that the proposed power plant unit will be CCS ready and that the criteria of the Directive were met.

Eivind Hoff from The Bellona Foundation says: "We conclude that instead of a real preparation for the future CCS application at Šoštanj, the process rather turned into a "box-ticking exercise" based on desk-top research and carried out well after the unit was designed."

The project promoters claim the unit will increase the efficiency of the plant, but in fact, this one lignite-fired power plant alone will create a huge carbon lock-in by swallowing up almost the entire carbon budget of the country by 2050. The Slovenian Ministry of Economy issued in April 2011 a damning report about the project, pointing to a huge risk of it being unprofitable.

The project is to benefit the financial support from the European Investment Bank in the amount of EUR 550 million and from the European Bank for Reconstruction and Development in the amount of EUR 100 million with a further EUR 100 million syndicated to commercial banks.

Download the report at:
www.bellona.org

GCCSI report - CCS 'competitive' in reducing power sector emissions

The GCCSI has released a report that concludes CCS is a competitive power sector emissions abatement tool when compared to other low-carbon technologies.

The 'Costs of CCS and other low-carbon technologies' study found that the cost of mitigating or avoiding CO2 emissions for a coal-fired power plant fitted with current CCS technology ranges from US$23-92 per tonne of CO2 and is a little higher for natural gas-fired power plants. This is compared to an avoided cost of US$90-176/tonne for offshore wind, US$139-201/tonne for solar thermal, and even more for solar PV.

Hydropower and onshore wind technologies were found to be among the least-cost technologies identified for reducing emissions from the power sector and are mature technologies that could be broadly deployed now.

Once these relatively low-cost technology options are fully exploited – because of limits in their availability – or in countries where these technologies are not an option, CCS becomes very competitive.

"Our findings are in line with International Energy Agency estimates which say that without CCS, abatement costs in the electricity sector could be higher by more than 70 per cent," said Barry Jones, General Manager for Policy and Membership at the GCCSI.

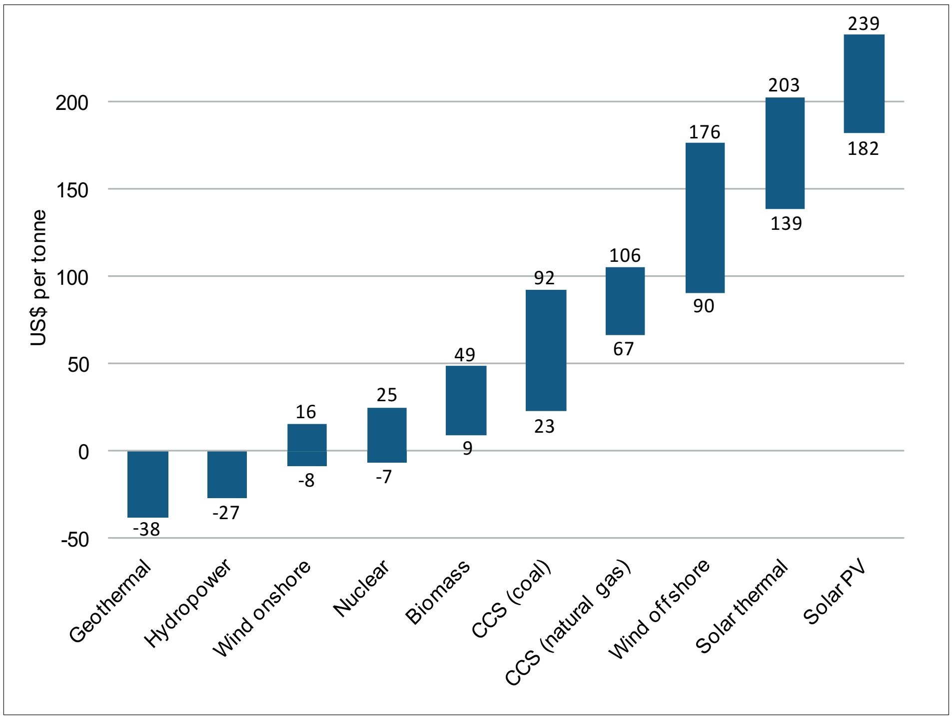
"It's important to note that costs of new technologies that have not reached full maturity, such as CCS, will become lower into the future."

The report concludes that taking the least-cost path to decarbonising the power sector requires a diversified mix of low-carbon technologies, and excluding CCS kwould increase total abatement costs.

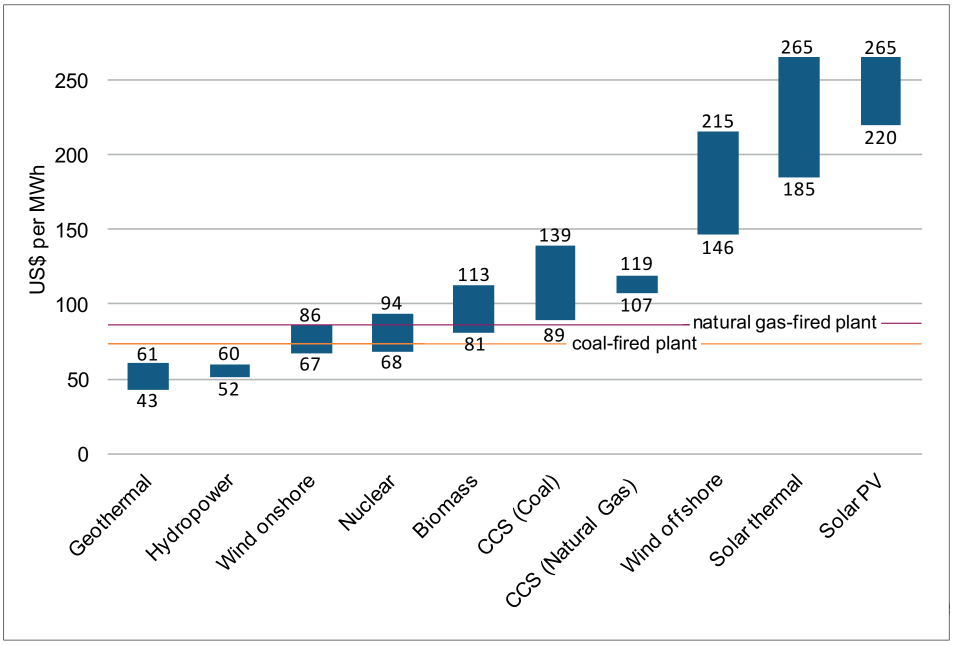
However, it warns that comparing the levelised costs of intermittent renewable technologies such as wind and solar with dispatchable technologies cannot be done easily given the variability and unpredictability of electricity production of solar and wind plants, which, in turn, affects their true economic value and profitability.

More information

Download the full report at:
www.globalccsinstitute.com



Cost of CO2 avoided
NOTE: For all technologies except gas-fired CCS plants, the amount of CO2 avoided is relative to the emissions of a supercritical pulverised coal plant. For gas-fired CCS, the reference plant is an unabated combined cycle plant.



Levelised cost of electricity of low-carbon technologies and conventional power generation

Policy, company and regulation news

SSE and Shell agree to work on Peterhead project

www.sse.com

A new joint development agreement has been signed between Scottish and Southern Energy (SSE) and Shell UK Limited (Shell) for the development of a CCS project at SSE's gas-fired power station in Peterhead, Scotland.

The agreement will enable the project to accelerate a programme of pre-FEED studies, with the intention that the project will be in a position to begin a full FEED study in the second half of 2012, subject to progress with funding proposals submitted under the European Union's NER300 process and developments in the UK's CCS demonstration programme.

The project aims to design and develop a full chain, post-combustion CCS facility capable of capturing carbon dioxide from a 385 MegaWatt combined-cycle gas turbine unit at Peterhead. It is planned that the CO2 will then be transported to the Shell-operated Goldeneye gas field in the North Sea using, as far as possible, existing infrastructure.

"The agreement between SSE and Shell is an important step forward for the development of CCS in Scotland and underlines the strong commitment of these two energy giants to the technology," said Scotland's First Minister Alex Salmond.

"Following the recent disappointment over Longannet and the previous UK Government's abandonment of the earlier Peterhead CCS project, it is essential that Westminster clearly demonstrates its commitment to supporting the commercial development of CCS, not least when the continued commitment from industry is so clear."

Report suggests CCS feasible in New Zealand

www.straterra.co.nz/ccs

The New Zealand Carbon Capture and Storage (NZCCS) Partnership, alongside Straterra, has released a report entitled "CCS in New Zealand – Case Studies for Commercial Scale Plant".

The NZCCS Partnership commissioned Transfield Worley to investigate the challenges facing CCS deployment in New Zealand.

The technical report, compiled in 2009, and companion summary conclude that CCS technologies could work safely and effectively in New Zealand.

Straterra CEO Chris Baker welcomed the report, stating "CCS needs help to progress, as do all technologies with low carbon intensity (including renewables). For instance, the regulatory regime is important and our laws do not easily support CCS development, adding to the cost and risk for companies to pursue CCS. This report highlights this and other issues."

Cambridge University research on CCS communication gaps

www.communicationnearco2.eu

Research at Cambridge Judge Business School has identified communication gaps that could hinder the deployment of CCS technologies.

Dr David Reiner's research team, together with colleagues from across Europe, has focused on how information about CCS is communicated, asking whether key lessons can be learned that will affect the technology's deployment.

A key step was to carry out a global review of CCS communication practices: who is communicating what aspects of CCS, and why? "We found that most CCS communication, which is principally via websites, is very good at explaining the technological processes involved.

But, in areas that are likely to be of most concern to society, such as costs, policy alternatives and wider social implications, there is scant coverage," said Dr Reiner. "Moreover, most of the information about CCS is from sources that are perceived by the general public as 'less trusted', such as business and governments, rather than research institutions, established media or NGOs."

These are serious obstacles believe the researchers, particularly as their findings indicate that environmentalists base their evaluations about CCS on what role they believe it will play in society rather than on whether they think CCS technology works or not. This view of environmental activists is based on data the researchers gathered in Climate Camps – grassroots movements that advocate direct action on climate change – and Green Party conferences in the UK. Participants at both displayed considerable understanding of the issues involved.

When it comes to the general public, though, the level of understanding of CCS was found to be considerably less. The research team investigated the opinions and perceptions of CCS by residents in five European Union member states who live in the region of planned projects.

"One major finding was that if the residents felt that the planning process was fair or that their local community had been treated fairly in the past, this had a direct relationship to their attitudes towards the local project," added Dr Reiner.

The researchers believe that improving communications and thinking more carefully about the social characteristics of the project at the design stage will reduce the likelihood of opposition. Under certain conditions, they found that even many strident environmental activists are willing to support (or at least not oppose) CCS.

"There is no magic formula," he added, "but taking the extra time needed to bring in more-trusted voices such as university scientists or environmental groups will increase the likelihood that these first projects, and ultimately CCS more generally, will be successful."

The University has recently launched the Cambridge Centre for Carbon Capture and Storage, which will facilitate collaborative research and act as a focal point for CCS research at Cambridge.

Alstom to do feasibility study for CCS at Daqing oil fields

www.alstom.com

China Datang Corporation (Datang) and Alstom have signed a feasibility study agreement for a CCS Demo Project in Daqing, Heilongjiang province.

This is another step for both parties in forming the long-term strategic partnership to develop carbon capture and storage (CCS) demonstration projects following the signing of an MOU in September this year. The agreement was signed in the presence of Mr. WANG Sen, Vice President of Datang and Philippe Joubert, Deputy CEO of Alstom.

According to the agreement, Alstom will carry out the study for the 350MW oxy-combustion CCS demonstration project located in Daqing, using its know-how and expertise in oxy-firing technology.

Scheduled for operation in 2015, the Daqing CCS demonstration project is the first large scale CCS demonstration project in China and Asia, capable of capturing above 1,000,000 metric tonnes of CO2 annually.

On top of the environmental benefits, the project also has potential for significant cost reduction in CCS projects. By utilizing Alstom's state-of-the-art CCS technology, leveraging extensive experience and expertise and adopting localized design and procurement, the project aims to establish the most cost effective CCS demo plant and set a benchmark for the CCS industry.

The Daqing CCS demonstration plant will be the first large-scale demo project to adopt the oxy-combustion technology, enriching the CCS technology mix in China.

Post combustion test bed development

Pacific Northwest National Laboratory (PNNL) assessment methodology and slip-stream testing platform enables the comprehensive early-stage evaluation of carbon capture solvents and sorbents utilizing a breadth of laboratory experimental capability as well as a testing platform at a nearby 600 MW pulverized coal-fired power plant.

By Jim Cabe, Dale King, Charlie Freeman, Pacific Northwest National Laboratory

Global research and development efforts are focused on the timely delivery and deployment of proven carbon capture technologies. Cost-effective carbon capture materials and unit-processes are a fundamental requirement for market penetration and facilitating the continued use of carbon-based energy resources.

While many new carbon capture technologies are being developed, it is often unclear whether they have undergone a thorough, systematic evaluation consistent with their stated Technology Readiness Level (TRL). To address this issue, PNNL, through their Energy Conversion Initiative, has incorporated a technology maturity and assessment methodology along with the necessary supporting laboratory, bench-scale, and engineering-scale level resources to objectively evaluate materials and processes from the fundamental molecular level, through materials synthesis and scale-up, and up through bench-scale operating conditions using actual slip-stream flue gas from a pulverized coal-fired power plant. The following provides a brief review of the methodology, modeling, and experimental tools used by PNNL to support the objective testing and evaluation of novel materials, as well as commercially available materials.

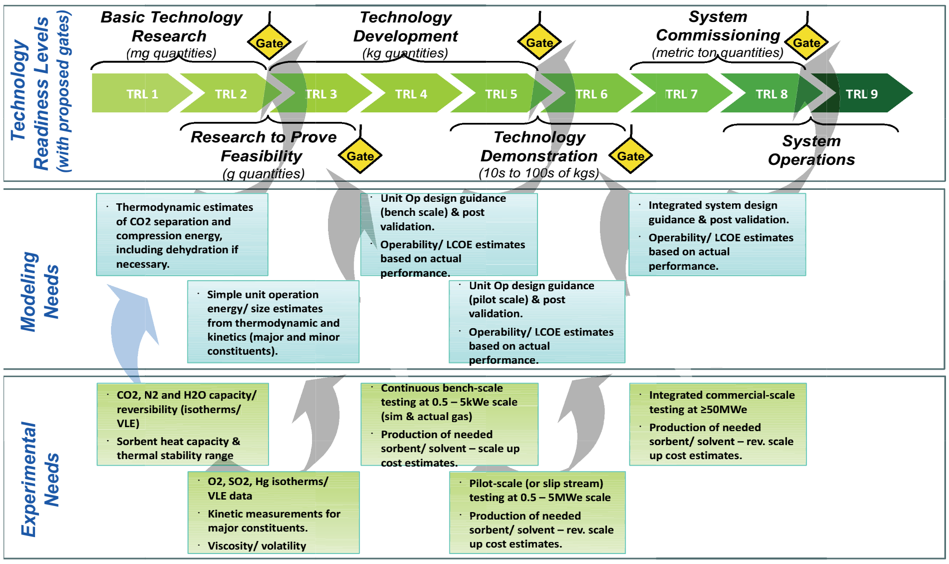


Figure 1 - TRL gate methodology - carbon capture technology development map - sorbents and solvents

From Theory to Product

There is no lack of research and development regarding carbon capture technology. The ongoing body of research has been a part of public and private investment for more than a decade and recognizes full commercial offerings in the industry.

However, specific to the development of novel technologies, what remains unclear is the efficacy of current technologies to meet the challenge of moving innovative carbon capture concepts from theory to proven operation. It's not that the TRL process itself is questionable; developed by NASA, the process has been effectively adapted to numerous industries and more recently by EPRI specifically for CO2 capture.[1] Rather, it's in the application of the TRL process when things become nebulous. While protocols at each respective TRL are descriptive, they are not particularly prescriptive.

This lack of a formal testing and validation structure enables researchers to provide experimental data relevant to them, but makes it difficult to corroborate or compare contextually based on what should be, at a minimum, key performance criteria at each respective TRL.

Because the environment is resource-limited, and time to commercial availability is paramount, an effective technology management process must be employed, which is not only capable of fostering the development of novel technologies, but also proficient at providing clear and tactical direction to research that has yet to begin, or is under consideration.

Originally developed to provide a prescriptive methodology for PNNL's internal assessment of carbon capture materials and processes, the "TRL-Gate" methodology, and supporting analytical equipment, has also been shown to be effective at characterizing products and processes being developed by collaborative research and development partners, as well as evaluating and validating those materials that are already commercially available. PNNL's TRL-Gate methodology for post-combustion carbon capture solid sorbent and solvent technology development is shown in Figure 1.

Figure 1 shows the flow of experimental, modeling, and gate decisions built into the TRL-Gate methodology. In this construct, TRL-1 corresponds to the observation and reporting of basic chemical and physical properties, and does not necessarily carry a corresponding gate decision criterion.

TRL-2, however, corresponds to the identification a material's fundamental thermodynamic characteristics. Analysis at this level would include equilibrium loading behavior at sorption partial pressures for the primary flue gas constituents (CO2, N2, and H2O). These measurements would allow the heat of reaction values for each gas to be determined. Additionally, measurements of heat capacity and thermal stability of the solvent or sorbent are prescribed.

Thermodynamic analyses of the TRL-2 data would be performed to determine minimum heat and work estimates achievable for a post-combustion process. The gate criteria at the end of TRL-2 is associated with over-

1. Electric Power Research Institute, Program on Technology Innovation: Post-Combustion CO2 Capture Technology Development, Report No. 1016995, Prepared by A.S. Bhown and B. Freeman, Palo Alto, CA, December 2008.

all separation and regeneration duties being less than 75% of an equivalent monoethanolamine (MEA) baseline projection.

Materials that have met the TRL-2 gate decision criteria would then be candidates for initiating TRL-3 testing. Analyses at this level include expanded thermodynamic testing to account for minor flue gas constituents, such as oxygen and sulfur oxides, along with kinetic sorption and desorption measurements and viscosity and volatility measurements for liquid materials.

Assessment tools used to analyze this, and the earlier information, include commercial packages such as AspenPlus™, ChemCad™ for solvents, and Adsim™ for solid sorbents. The criteria for passing the TRL-3 gate include a revised regeneration energy estimate compared to MEA, along with estimates of process footprint and material scale-up costs.

It is noted that the success or failure of a material at a specific TRL level is not based solely on static empirics, nor does it suggest that a material should be eliminated from further consideration if it does not meet all of the threshold criteria. Rather, it drives an informed decision-making process.

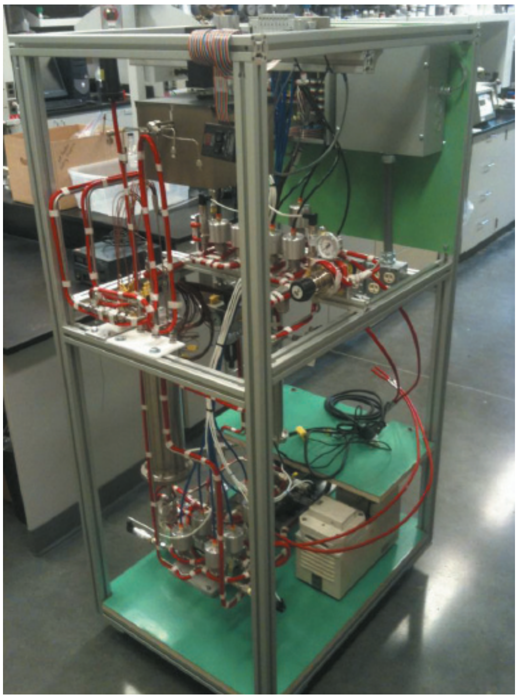


Figure 2 - CO2 solvent (left) and solid sorbent (right) test carts

For example, a material at TRL-3 may demonstrate tremendous reversibility and attractive kinetics when compared to MEA, but struggle to meet viscosity targets, thereby affecting the pumping energy required. While the material may not be acceptable for a TRL-4 analysis, future research should reflect the effort to reduce this effect.

This may be accomplished through modification at the molecular level, or it may be accomplished via a process modification. In any event, the application of the TRL-Gate process should provide clear and meaningful direction. Once comparatively baselined, if acceptable, the materials may initiate evaluation at the TRL-4.

From Product to Process

TRL-4 and TRL-5 correspond with laboratory bench-scale testing using simulated and actual flue gas. At this level in the TRL-Gate process, materials that have passed previous gate criteria are assessed in an integrated system representative of an actual process configuration at an appropriate scale. PNNL has developed mobile cart-based systems for both liquid and solid sorbents as a means of testing at both of these levels.

The carts were designed for a maximum feed gas (flue gas) flow rate of 30 standard liters per minute, corresponding to approximately 0.5 kg/hr of CO_2 when considering common flue gas compositions. The liquid solvent cart (left-hand photograph in Figure 2) is configured with an absorption and stripping column, and can be operated in either single-bed or dual-bed mode depending on desired analytics. The solid sorbent cart (right-hand photograph in Figure 2) is configured as a two-bed adsorption test system that can be programmed to operate in single-bed Temperature Swing Adsorption (TSA), single-bed Vacuum Swing Adsorption (VSA), two-bed TSA, two-bed VSA, or combined TSA-VSA modes. Both of these systems have been operated in laboratory environments and with actual flue gas at a nearby coal-fired power plant.

To date, commercially available materials, such as MEA and 13X-zeolite have been demonstrated in these systems for commissioning purposes. The data and analytics from the runs have been assessed against publicly available literature, as well as internally developed models, and compare favorably to both.

Based on data generated by the cart systems, more accurate performance data can be incorporated into the modeling tools to represent longer-term material performance and overall energy consumption. These projections, as well as general confirmation of system operability, are key gate decision criteria leading into TRL-6 and higher, which represents pilot and commercial-scale demonstrations.

Concluding remarks

Acknowledging that the R&D environment is resource-limited, the advancement of promising materials and technologies must be completed expediently yet comprehensively. With programs such as the Department of Energy's Carbon Capture Simulation Initiative pulling together solutions from partnerships with national labs, academia, and industry comes the recognition that the requisite equipment, expertise, and expense are likely beyond any one organization.

PNNL, by focusing on early stage TRL assessments, is using its structured methodology and supporting analytics to screen candidate materials, thereby accelerating the development of those that meet the prescriptive gate criteria, while providing direction to those that don't. While the work to date has focused on a methodology for assessing solid sorbents and solvents only, a similar structure is envisioned for other types of carbon capture technologies.

More information

Pacific Northwest National Laboratory, located in Richland, Washington, is one of ten U.S. Department of Energy (DOE) national laboratories managed by DOE's Office of Science. It focusses on problems in energy, the environment and national security.

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Capture news

Statoil selects technology suppliers for Mongstad

www.statoil.com

Gassnova and Statoil have chosen suppliers of CO_2 capture technology to participate in a technology qualification program for full-scale CO_2 capture at Mongstad (CCM).

Successful results in the technology qualification program should allow for selection of the technology in first half of 2014, Statoil said.

The technology qualification program for all companies which have technology that could be used to capture CO_2 from the existing combined heat and power plant at Mongstad has been ongoing for several months.

It was an open international process where the goal was to select companies for technology qualification for full scale capture of CO_2.

The following companies have been selected to participate in the technology qualification program: Mitsubishi Heavy Industries, LTD., ALSTOM Carbon Capture GmbH, Siemens AG, Aker Clean Carbon and Huaneng-CERI Powerspan Joint Venture. The purpose of the technology qualification program is to qualify at least one technology and demonstrate that it can be scaled up and used at the combined heat and power plant at Mongstad, and that it will meet all HSE requirements.

The technology qualification program is divided into three phases:

- Feasibility study to show that the technology can be used at Mongstad. Companies must demonstrate that technologies can be scaled up; that they have the necessary operational regularity; and that high capture ratios are possible to achieve in relation to energy use and costs, for example.

- Demonstrate that the process will work and that the emissions will be within the specified criteria. This shall include vendors' test of chemical and process technology so that real emission data can be analysed and evaluated based on the limit set for release at Mongstad.

- Concept Phase for design of full scale CO_2 capture at Mongstad.

"CCM is a very large industrial and technological development project, and a plant of similar size has never been built before," said Kurt Georgsen, vice president in Renewable Energy and responsible for CCM. "For Statoil, it is very important that the system works as intended and does not represent any danger to people or the environment."

The Mongstad test plant (Photo: HELGE HANSEN / Statoil)

"For CO_2 capture technology in general, it is also important that the project shows that CCS can be accomplished elsewhere: therefore it is of great importance that there is a responsible project implementation that takes care of uncertainties in the best possible way, ensuring the best technical solutions at the lowest possible cost."

Participation in the technology qualification program will provide technology suppliers with an opportunity to demonstrate its technology for a full-scale plant at Mongstad.

Multiple vendors can then bid on a FEED (Front End Engineering and Design) based on the concept selected, and the final investment decision will be put forward to the Norwegian Parliament in 2016.

CO2 capture project receives CSLF recognition

www.co2captureproject.com

The CO_2 Capture Project (CCP) has received recognition from the Carbon Sequestration Leadership Forum (CSLF) for its contribution to the advancement of CO_2 Capture and Storage (CCS).

The CCP is a partnership of several energy companies, working to develop and test CCS technologies.

The CSLF recognised the CCP's third phase (CCP3; 2009-2013) which is focussed on field demonstrations of capture technologies and a series of field trials which will provide an understanding of how to monitor CO_2 in the subsurface.

The CO_2 Capture Project also received a CSLF Recognition Award for the second phase of its project (CCP2), which was completed in 2009.

Summit Power forms carbon capture division

www.summitpower.com

Summit Power has formed a new unit within the company - Summit Carbon Capture.

The company has hired Mr. Sasha Mackler as vice president of the new unit. Mr. Mackler was a founding member of the Bipartisan Policy Center's Energy Project, which played a key role in drafting recent Federal energy laws.

In his new role, Mr. Mackler will help manage commercial and policy aspects of the company's carbon capture initiatives. He will focus on carbon capture power projects and emerging technologies, as well as business opportunities for climate-friendly commercial uses of captured carbon such as enhanced oil production.

Summit is developing several CCS projects, most notably the Texas Clean Energy Project (TCEP), a gasification facility with 90% carbon capture that will produce electric power and fertilizer, as well as captured carbon dioxide.

SNC-Lavalin joins Sargas CO2 capture alliance

www.sargas.no

Sargas and Daewoo Shipbuilding & Marine Engineering (DSME) have joined with SNC-Lavalin to build CO2 capture plants based on Norwegian Sargas technology.

Sargas has patented a system for capturing CO2 from flue gas that uses a high gas pressure, which it says improves efficiency and reduces space.

The companies have signed an alliance to develop power plant applications with CCS Project opportunities using the Sargas technology.

DSME will pre-assemble the Sargas designed plants in its shipyard in Korea and SNC-Lavalin will manage the projects and execute engineering and local site construction.

They are currently working on commercial carbon capture opportunities in Europe, North America and MEA (Middle East and Africa).

UK carbon mineralization research project agreed

www.polarcus.com

Polarcus Ltd and Cambridge Carbon Capture Ltd (CCC) will collaborate on a research project to develop carbon mineralization technology.

The technology could potentially be used to reduce CO2 emissions from ships, including emissions from Polarcus' fleet of 3D seismic vessels.

As part of the agreement Polarcus and CCC have agreed to jointly fund a 3 year Ph.D. research program at the University of Sheffield. The program will operate under the "E-Futures Doctoral Training Centre" scheme operated at the university.

Cambridge Carbon Capture's electrochemical technology generates electrical power from hydrocarbons while capturing and permanently storing CO2 via a mineralisation reaction with Ca/Mg silicates or wastes. It is working with a number of partners to develop the technology.

New UK CCS training academy announced

www.ccstlm.com

CCS TLM and The National Centre for CCS (NCCCS) have launched an academy offering training courses in carbon capture and storage.

The academy will develop and run a series of short (2-3 day) training courses aimed at improving knowledge and understanding of the CCS business.

The courses on offer will be aimed at personnel in industry and other key stakeholders who may be involved in CCS in the future, or those who need to have a technical overview about CCS but are not able to undertake lengthy periods of training.

The first course, in London on Jan 11-12, 2012, will feature an introduction to the theoretical, practical and commercial aspects of the carbon capture and storage industry, including instruction from trainers with direct project experience and covering the full value chain, not just capture or storage.

A risk based approach for verification of CO2 storage capacity estimation

There is an increasing need to focus on questions of CO2 storage capacity without compromising the safety or integrity of the storage site. Documentation of safe long term storage of large volumes of CO2 in geological formations is one of these challenges.

By Semere Solomon, DNV

Governments around the world are dependent on reliable estimates of CO2 storage capacity in order to get insight on the viability of geological storage in their respective jurisdictions. On the other hand, industry needs reliable estimates for business decisions regarding site selection and development.

Moreover project developers have to demonstrate that the storage site has the intended storage capacity while securing safety (no harm to life, human health and the environment) and that the CO2 is permanently stored (climate benefit of the project).

To build confidence among stakeholders (regulators and the public) a transparent procedure for verifying the storage capacity estimates is deemed necessary. In this article the main focus will be details on the procedures for verification of storage capacity estimates which is founded on the DNV's principles of the risk based verification (RBV) concept.

Existing methods and challenges

The methods available for estimating subsurface volumes to date are widely and routinely applied in oil and gas, ground water, underground natural gas storage, and underground waste/fluid disposal-related estimations. In general, these methods can be divided into two categories: static and dynamic. The static models are the volumetric model and the compressibility model; the dynamic models are decline curve analyses, material balance, and reservoir simulation (see for details, USDOE 2008).

Oil and gas reservoirs: In the case of oil and gas reservoirs, the fundamental assumption is that the volume previously occupied by the produced hydrocarbons becomes, by and large, available for CO2 storage and the capacities are calculated on the basis of reservoir properties such as original oil or gas in place, recovery factor, temperature, pressure, rock volume and porosity, as well as in situ CO2 characteristics such as phase behavior and density.

This assumption is generally valid for reservoirs that are not in hydrodynamic contact with an aquifer, or that are not flooded during secondary and tertiary oil recovery. However, many reservoirs are subjected to flooding for either recovery or pressure maintenance purposes and could be in hydrodynamic contact with aquifers. Also not all the previously hydrocarbon-saturated pore space will become available for CO2 because some residual water may be trapped in the pore space due to capillarity, viscous fingering and gravity effects (Bach et al. 2007).

Another known assumption is that CO2 will be injected into depleted oil and gas reservoirs until the reservoir pressure reaches the original pressure. In some cases reservoir depletion may damage the integrity of the cap rock, in which case the pressure cannot be brought back to the initial reservoir pressure and the capacity would be lower (Bach et al. 2007).

Deep saline aquifer: For assessing the CO2 storage capacity in saline aquifers the same methods are used. Moreover, a number of analytical models are developed by many workers which are based either on the static or dynamic approach. Again all the analytical methods are based on a number of assumptions. The most common include: simple aquifer geometry, constant reservoir characteristics and different assumptions about trapping mechanisms as well as the derivation of effective storage coefficient values.

According to Bachu et al. (2007) some of the barriers to CO2 storage capacity estimates, among others include:

- Lack of consistent methodologies and guidelines for capacity estimations;
- Proper documentation regarding data;
- Constraints and methodologies used;
- Proper reporting procedures and practices.

These are the main challenges today for CO2 storage capacity estimation. The various assumptions will further add more uncertainty to the estimated capacities. Today both industry and governments are facing these challenges. To overcome these challenges it is considered rational to use an RBV approach for CO2 storage capacity estimation. This approach focuses on the risk and associated uncertainty involved in the estimation and is believed to contribute in making reasonable decisions and building the confidence among stakeholders. This approach can be applied to the desired scale and to any stage in the project phase as illustrated in the CO2QUALSTORE Guideline (2010).

Figure 1 - the DNV risk verification chain

Risk Based Verification concept

RBV procedure for CO2 storage capacity estimates is founded on the Det Norske Veritas (DNV) offshore service specification for risk-based verification, state-of-the-art methodologies within Verification and validation, and recognized methods for CO2 storage capacity estimation. The risk based verification concept is described in DNV-OSS-300 (Det Norske Veritas 2004) and is presented in Fig. 1.

Verification constitutes a systematic and independent examination of the various lifecycle phases of an asset (in this case CO2 storage capacity) and provision of objective evidence that the specified requirements have

been fulfilled. The examination shall be based on information which can be proved true, based on facts obtained through observation, measurement, test or other means.

Thus, the overall general steps for CO2 storage capacity estimation (CSCE) that can be applied at the desired scale(s) and any project stage is presented in Fig. 2 and provides the framework for the verification plan. The following is addressed in the procedure:

• A generalized procedure for CSCE constitutes the framework in which the verification is performed. This framework is based on recognized methods for CSCE.

• Description of detailed topics in the verification procedure such as CO2 storage capacity specification, risk assessment and definition of verification involvement by three risk-based verification levels.

• Development and execution of the verification plan that includes a description of how the different steps in the general framework for CSCE will be verified for the different levels of verification.

If the validation results show that the estimated storage capacity is not reliable for the evaluation goal then one has to return to step 2 and perform the sequence again, i.e. it is an iterative procedure. Generally, validation results indicate how to improve the estimated results.

It is recommended to document every action taken in each step of the evaluation of the storage capacity estimation process. This is particularly useful when the estimation made is based on large uncertainty due to poor data quality, and when several important parameters that need to be included in the calculation of the capacity are not considered. At the end, a report summarizing all the necessary details about the CSCE should be prepared.

Verification of CO2 storage capacity estimates

This section describes important and detailed aspects related to the verification procedure. This includes planning, capacity specification, risk assessment, determination of verification level and the verification plan of the DNV risk based verification concepts for CSCE.

1. Storage capacity/reserve planned: This is the starting point for the CO2 storage potential evaluation project and is the decision of the owner. It may comprise a general description of the project in the form of functionality, safety, capacity, economics etc.

2. Storage capacity specification: Storage capacity specification has been identified as a separate element to focus on the need to address objectives, acceptance criteria and performance requirements to the storage site.

At least the following need to be specified at this step:

• Storage site description: A full picture about the storage site physical geometry, available data, geological and reservoir constraints, storage integrity related issues such as presence of faults and abandoned wellbores including the seal characteristics in the storage complex should be provided. To define a storage capacity potential, we need to specify the boundaries of the reservoir, including mapping of potential leak pathways.

• The capacity estimation goal: Specifies what one wants to achieve with the estimated capacities. The goal has a major impact on the level of detail and on the method of calculation required.

• Acceptance criteria or performance requirements for the storage site for which the capacity to be estimated.

• Determination of overall verification plan.

3. Risk assessment: The risk assessment is a means to determine the required level of verification. The risk assessment includes the identification of hazards, frequencies of occurrence, consequences and risk drivers. It also includes ranking of hazards based on risk evaluation.

The risk can be defined on a general level, for different phases or for detailed elements of the capacity estimation. Risks with CSCE are that it fails to give expected results because of aspects such as:

The calculation was based on several assumptions (realistic or unrealistic)

The storage site for which its capacity to be estimated has inherent complexity but oversimplification or lack of data may lead to erroneous estimations. These simplifications may distort the results to an extent that these become neither meaningful nor useful in the decision making process.

Consequences of such failure can be the following:

• Incorrect decisions

• Delay in making decisions

• Loss of time, resource and money

4. Definition of verification involvement: The level of verification involvement should be differentiated according to the risk to the asset or elements or phases thereof. If the risk to the asset is higher, the level of verification involvement is higher. Conversely, if the risk to the asset is lower, the level of verification activities can be reduced, without any reduction in their effectiveness.

There are three levels of verification of assets, categorized as low, medium and high. Low is the level of verification applied where the risks to the asset are lower than average. For example it has benign contents, it is located in congenial environment conditions, or the contractors are well experienced in the evaluation of similar assets. The level may also be appropriate when the owner (or other parties) performs a large degree of verification or quality assurance work.

With regard to CO2 storage capacity verification, the Low category of verification may apply in the following example situations:

• The storage site for which the estimation of capacity to be made is well characterized with sufficient data coverage.

• The reservoir quality is good (e.g. relatively uniform porosity/permeability, good connectivity, few/no flow barriers, no real limiting high risk leak paths that must be avoided which significantly constrains capacity).

If the verification of the asset/reserve is done as part of the CO2 storage capacity estimation steps described above by experienced personnel no independent verification is required.

Medium is the level of verification applied where the risks to the asset are average. This is the level of verification which is customary and is applied to the majority of assets. For CO2 storage capacity verification, this category of verification may apply in the following example situations:

• When there is mismatch between theoretical capacity estimates and estimates derived through simulation because of the need for multiple distributed wells to meet system capacity requirements or the need for reduced injection volumes.

• Limited data coverage and low level of site characterization

• The verification of the capacity estimates may require independent verification.

High is the level of verification applied where the risks to the asset is higher than average. For example, the site is characterized by a highly complex geology, available data is insufficient to characterize the site, it is evaluat-

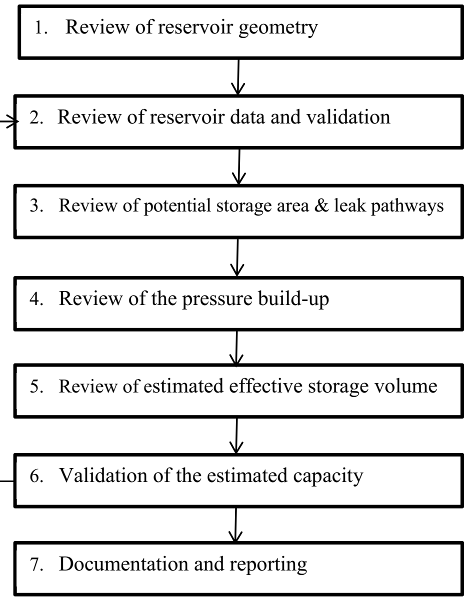

Figure 2 - general steps in CO2 storage capacity estimation verification

ed using new methods which may be innovative or the contractors are not well experienced in performing the tasks in similar assets. This level may also be appropriate when the owner chooses to have a small technical involvement or perform little own verification.

For CSCE verification, the High category of verification may apply in the following example situations:

• When capacity has initially been assessed to be sufficient, but either pressure is increasing faster than predicted, unexpected compartmentalization of reservoir is observed or pressure constraints are reduced (e.g., due to fracturing).

• New containment risks are observed (or level of existing containment risks increased) that may constrain ability to utilize capacity.

• The owner of the asset is not involved in the estimation and uses contractors for the evaluation work.

Independent verification is strongly recommended for High level verification.

5. Develop verification plan: This section describes how to develop the verification plan including a list of verification activities. The verification plan is developed based on compliance with the general framework for CSCE shown in Fig. 2 and the determined verification level for the estimation.

A questionnaire based approach is proposed for the verification in each step. Each question indicates the levels of verification, i.e. the question is addressed. 'L', 'M' and 'H' to denote low level, medium level and high level verification, respectively. Typical verification plan is shown in Table 1. For simplicity examples from the general framework for CSCE, a few lists of verification activities are selected for illustration purposes.

6. Verification execution: Verification execution is document review, independent analyses, inspection, monitoring (cross-validation), site visits, process audits, technical audits, testing, etc. according to the verification plan. Information arising from execution should be used to identify continuous improvements to the verification plan. The purpose of the verification activities is to confirm compliance or non-compliance with the capacity specification or other regulatory requirements.

7. Asset evaluation completed: Asset evaluation completed is the end point of any lifecycle phase or phases, which complies with the relevant planned resource estimation and the capacity specification and other regulatory requirements on integrity and safety of storage sites.

Verification activity	Level		
	L	M	H
1. Review of reservoir geometry			
• Is the reservoir physically defined	X	X	X
• What are the dimensions in terms of length, widt		X	
• How deep is the reservoir?		X	X
2. Review of reservoir data and validation			
• Are the porosity and permeability of the storage			X
• Is the reservoir homogeneous or not?			X
• What are the reservoir temperature and pressure	X	X	
3. Review of potential storage area and leak pathways			
• Do stratigraphic pinchouts exist and mapped?			X
• Do high pearmeability streaks exist and mapped?		X	X
• Do bounding faults exist and are mapped?		X	
4. Review of the pressure build-up (PBU)			
• How is the PBU determined?			X
• What is the PBU development in the reservoir do injection period?		X	X
• Does the PBU have the potential for creation reactivation of unidentified faults?	X	X	
5. Review of estimated effective storage volume			
• Is the total available storage volume calculate the potential leak pathways?		X	
• How is the storage capacity determined?	X		
• Is pressure build-up taken into account in the c		X	X
6. Validate and verify estimated capacity (verificati			
• Are the estimations confirmed by dynamic modelli			X
• Isthe data used site specific?			X
• Have the results been discussed with the client agreed and documented?		X	
7. Documentation and reporting			
• Has all the work been properly documented?		X	
• Has the owner reviewed the report and agreed with the report's findings?		X	
• Is the documentation unambiguous?	X		

Table 1 - typical verification plan for CSCE with a list of selected verification activities

Conclusion

This article provides the procedures for verification of storage capacity estimates by developing a framework which is founded on the DNV's principles of the risk based verification concept that can be applied to the desired scale as well as stage of the project as presented in the CO2QUALSTORE guideline. In the absence of standardized methods of CO2 storage capacity estimation a risk based verification approach is both necessary and rational to build confidence among the stakeholders. Application of the protocol will address uncertainty and risks associated with investment decision making, safety and environmental issues and thus can facilitate decision making and provides confidence and trust to the stakeholders.

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About the author

Semere Solomon is a Geologist with a PhD and 13 years of broad professional experience in different field areas in applied geosciences (e.g. reservoir geology, structural geology & rock mechanics and hydrogeology). At DNV Semere is currently working as a Principal Specialist in underground storage of CO2 in issues related to storage capacity, wellbore integrity, reservoir geomechanics including overall storage integrity.

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Transport and storage news

IPAC-CO2 releases CO2 storage standard

www.ipac-co2.com

The draft of the world's first standard for geologic storage of carbon dioxide now is available for public review.

Feedback can be provided online through the CSA Standards public review system on a clause by clause basis.

CSA Standards, a leading developer of standards, codes and personnel certification programs since 1919, and the International Performance Assessment Centre for Geologic Storage of Carbon Dioxide (IPAC-CO2) began work on June 16, 2010 on the new standard.

A Technical Committee (TC) comprising almost three dozen experts from Canada and the United States began reviewing the seed document IPAC-CO2 had prepared to form the basis of the standard on November 24.

Rick Chalaturnyk, a geotechnical engineering professor and holder of the Foundation CMB Endowed Chair in Reservoir Geomechanics at the University of Alberta in Edmonton, is the chair of the TC.

Sara Forbes, who leads the CCS work at the World Resources Institute (WRI) in Washington, D.C., is the vice-chair of the TC.

Upon completion, the new standard will provide essential guidelines for regulators, industry and others around the world involved with scientific and commercial CCS projects.

The new standard will be submitted to the Standards Council of Canada and ANSI in the United States for bi-lateral recognition making it the world's first formally recognized CCS standard in this area.

The new standard will provide the basis for development of the international standards by the International Organization for Standardization (ISO).

John Wood Group to conduct UK CO2 storage study

www.woodgroup.com

John Wood Group has been appointed by the UK National Grid to perform study work in relation to development options for underground carbon dioxide storage in the U.K. sector of the southern North Sea.

The work will be undertaken by Wood Group's subsidiaries Wood Group Kenny, a specialist subsea engineering and management contractor and Wood Group Mustang, an engineering, design, project management, and construction management firm.

Leading the work from its Aberdeen office, Wood Group will design concepts of the offshore surface facilities as well as scheduling and cost estimating for offshore pipeline and subsea facilities, it said.

"This project is one of a number we are considering in our quest to assist the UK Government to meet its obligation to cut carbon emissions by 20 per cent by 2020," said Russell Cooper, National Grid Carbon, CCS Technical Lead.

Work commences at Thunderbird Energy's Gordon Creek gas field

www.thunderbirdenergy.com

The U.S. Southwest Regional Partnership on Carbon Sequestration's CCS storage project Phase III has started.

Drilling and workover operations have begun at Thunderbird Energy's Gordon Creek natural gas field.

The field activities will include a 3D seismic shoot to gain further understanding of the structure that is believed to host the previously discovered CO2 at Gordon Creek.

The project will also be re-working the existing injection well at Gordon Creek in order to conduct a high rate combine CO2-Water injectivity test.

A program of 50 new wells and 5 workovers of existing wells will be carried out in 2011 and 2012.

Operations at Thunderbird Energy's Gordon Creek gas field

DNV issues first certificate of fitness for CO2 storage

www.dnv.com

DNV has awarded the world's first certificate of fitness for safe CO2 storage to Shell's Quest Carbon Capture and Storage project.

The proposed Quest project will capture and permanently store underground more than one million tonnes of CO2 per year from its Scotford Upgrader, located near Fort Saskatchewan, Alberta.

DNV, together with industry and governments, has recently developed recommended guidelines and best practices for CO2 geological storage selection and risk assessment, and were commissioned by Shell to coordinate a comprehensive review to assess the suitability of the Quest project's underground storage formation to safely and permanently store injected CO2.

The review also assessed the project's measurement, monitoring and verification program to validate that it would provide the necessary rigor to demonstrate effective containment. DNV assembled a panel of seven CCS experts from academia and research institutions to perform the review over a two-week period.

"Through developing guidelines and standards for CCS in collaboration with governments and industry, DNV has taken an instrumental role towards paving the way for safe and cost-effective deployment of CCS," said Jørg Aarnes, Principal Consultant, DNV. "But while regulations, guidelines and standards may help clarify the rules of the game, the main challenge is demonstrating compliance with these rules. The expert panel validation of the Quest storage development plan is a first of its kind in the world and provides independent assurance to stakeholders that CO2 storage will be safely and responsibly managed."

CCS operators must perform extensive analysis and data collection to assess, validate and provide assurance to regulators and stakeholders that a particular set of geological formations is suitable for CO2 storage. Evidence must be provided to show that injected volumes of purified CO2 will be isolated and retained in the geological formations and that any associated risk to the environment is carefully managed through a tailored monitoring and verification program.

Validation of CO2 storage sites is a significant challenge because it requires a thorough understanding of the local geology and the behaviour that carbon dioxide exhibits when injected deep underground. Based on the conclusions of the expert panel DNV certified that Shell's Storage Development Plan is fit for purpose based upon a number of different metrics, such as: sufficient storage capacity, long-term containment, proper risk management plans, and a measurement, monitoring and verification program capable of continuously demonstrating containment.

Status of CCS project database

The status of 78 large-scale integrated projects data courtesy of the Global CCS Institute

For the full list, with the latest data as it becomes available, please see the pdf version online at www.carboncapturejournal.com or download a spreadsheet at www.globalccsinstitute.com/resources/data

Asset Lifecycle Stage	Project Name	Description	Country
Operate	**Century Plant (formerly Occidental Gas Processing 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.	UNITED STATES
Operate	**Enid Fertilizer**	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.	UNITED STATES
Operate	**Great Plains Synfuel Plant and Weyburn-Midale Project**	About 3 million tonnes per annum 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 and Midale Oil Fields.	CANADA
Operate	**In Salah CO2 Storage**	In Salah is a fully operational onshore gas field in Algeria. Since 2004, 1 million tonnes per annum of carbon dioxide are separated from produced gas and reinjected into the producing hydrocarbon reservoir zones for storage in a deep saline formation.	ALGERIA
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.	UNITED STATES
Operate	**Sleipner CO2 Injection**	Sleipner is an operational offshore gas field with carbon dioxide injection. The carbon dioxide is separated from produced gas and reinjected into a deep saline formation above the hydrocarbon reservoir zone. This project has been in operation since 1996.	NORWAY
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.	NORWAY
Operate	**Val Verde Natural Gas Plants (formerly Sharon Ridge)**	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.	UNITED STATES
Execute	**ADM Illinois Industrial Carbon Capture and Sequestration 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.	UNITED STATES
Execute	**Agrium CO2 Capture with ACTL**	Agrium's fertiliser plant in Alberta is 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.	CANADA
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.	CANADA
Execute	**Gorgon Carbon Dioxide Injection Project**	This component of a larger gas production and LNG processing project will inject 3.4 to 4 million tonnes of carbon dioxide per annum into a deep saline formation. Construction is under way after a final investment decision was made in September 2009.	AUSTRALIA
Execute	**Kemper County IGCC Project (formerly Plant Ratcliffe)**	Mississippi Power (Southern Company) is constructing an air-blown 582 MW 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.	UNITED STATES
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.	UNITED STATES
Define	**Air Products Steam Methane Reformer EOR Project**	This project proposes to capture more than 1 million tonnes per year of carbon dioxide from two steam methane reformers to be transported via Denbury's Midwest pipeline to the Hastings and Oyster Bayou oil fields for enhanced oil recovery.	UNITED STATES

State / District	Volume CO_2	Operation Date	Facility Details	Capture Type	Transport Length	Transport Type	Storage Type	Project URL
Texas	8.5 Mtpa	2010	Natural Gas Processing	Pre-Combustion	256 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.oxy.com/
Oklahoma	0.68 Mtpa	1982	Fertiliser Production	Pre-Combustion	192 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.kochfertilizer.com/
Saskatchewan	3 Mtpa	2000	Synthetic Natural Gas	Pre-Combustion	315 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.cenovus.com/
Wilaya de Ouargla	1 Mtpa	2004	Natural Gas Processing	Pre-Combustion	14 km	Onshore to onshore pipeline	Onshore Saline Formations	http://www.insalahco2.com/
Wyoming	7 Mtpa	1986	Natural Gas Processing	Pre-Combustion	190 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.exxonmobil.com
North Sea	1 Mtpa	1996	Natural Gas Processing	Pre-Combustion	Minimal (storage on site)	Offshore to offshore pipeline	Offshore Saline Formations	http://www.statoil.com/en/
Barents Sea	0.7 Mtpa	2008	Natural Gas Processing	Pre-Combustion	150 km	Onshore to offshore pipeline	Offshore Saline Formations	http://www.statoil.com/en/
Texas	0.4 - 1.3 Mtpa	1972	Natural Gas Processing	Pre-Combustion	132 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.exxonmobil.com/
Illinois	Up to 1 Mtpa	2013	Chemical Production	Industrial Separation	1.6 km	Onshore to onshore pipeline	Onshore Saline Formations	http://www.adm.com/
Alberta	0.585 Mtpa	2014	Fertiliser Production	Pre-Combustion	234 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.agrium.com/
Saskatchewan	1 Mtpa	2014	Power Generation	Post-Combustion	100 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.saskpower.com/
Western Australia	3.4 - 4 Mtpa	2015	Natural Gas Processing	Pre-Combustion	10 km	Onshore to onshore pipeline	Onshore Saline Formations	http://www.chevronaustralia.com/
Mississippi	3.5 Mtpa	2014	Power Generation	Pre-Combustion	75 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.mississippipower.com/
Wyoming	1 Mtpa	2012	Natural Gas Processing	Pre-Combustion	370 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.conocophillips.com/
Texas	1 Mtpa	2012	Hydrogen Production	Pre-Combustion	Not specified	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.airproducts.com/