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Front cover: The Cansolv CO2 & SO2 capture plant at SaskPower's Boundary Dam power plant, currently under construction, will start to capture CO2 by the end of 2013

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Cansolv: capturing attention at Boundary Dam

Cansolv Technologies Inc. (CTI) is providing the CO_2 capture technology for SaskPower's Boundary Dam project, which will begin capturing CO_2 in late 2013.

Author: Devin Shaw

As a selected technology provider on the Boundary Dam project, CTI is eager to see the project advance to fruition and start to capture CO_2 in late 2013. This will be the first commercial scale application of the CANSOLV CO_2 capture technology, which goes without saying as it will be the first commercial scale post-combustion Carbon Capture and Sequestration (CCS) project of its kind in the world. As shown by its on-schedule construction status, SaskPower is well on its way to recognizing this exciting milestone.

Just as SaskPower are pioneers in CCS, CTI are also pioneers – in the world of regenerable fluegas scrubbing. CTI were the first to apply and commercialize amines in the application of post-combustion, oxidative fluegas scrubbing. Amines, such as MEA or DMEA, have been used for regenerable scrubbing in the Oil & Gas world for many decades. It is common practice to use such an amine to remove pollutants such as Hydrogen Sulfide (H_2S) and/or Carbon Dioxide (CO_2) from natural gas streams or refinery gas streams to purify them and render them ready for sale.

Figure 1 - Cansolv CO2 capture plant (©SaskPower 2006)

This is an application performed on the raw gas itself – before any combustion or use thereof and therefore at high concentrations and pressures. And also, importantly, since the gas has not yet been combusted: without the presence of oxygen. CTI developed the concept of a regenerable amine process and applied it in a post-combustion environment – which implies low-pressure gas (close to atmospheric pressures) and of course containing the presence of oxygen. As redundant as it may sound, oxygen is of course a fantastic "oxidizer" of many things; amines are no exception.

It was the careful consideration of how to handle and manage the use of an amine in this type of environment where CTI excelled and eventually succeeded in commercializing the use of this unique technology. Another unique element, pioneered by CTI, was the use of amines in scrubbing sulfur dioxide (SO_2) instead of H_2S or CO_2 – which is at the heart of the patents and the key differentiator of the technology; but this is the topic of another article.

SaskPower and CTI have been working together since 2006, when SaskPower engaged CTI to run a short pilot campaign at their Poplar River power station (see Figure 1 below). The CANSOLV technology had intrigued SaskPower enough that they wanted to learn more about it. The campaign saw CTI send a mobile 'multi-pollutant capture plant' to the SaskPower site to treat a small slipstream of the coal-fired power plant fluegas for SO_2 & CO_2 removal.

As the only provider of amine based regenerable SO_2 and CO_2 scrubbing technologies, CTI is uniquely positioned to offer an integrated system that uses the same technology to sequentially scrub SO_2 and CO_2 in one system. Since the two processes are the same (the flowsheets are nearly identical), CANSOLV can also take advantage of some internal synergies to recover energy and thus lower the overall energy demand.

It is no secret that a significant downfall of these types of CO_2 capture plants is the parasitic consumption of low pressure steam. When applied at a power station, where steam translates to electricity to the grid, this is a critical parameter in selecting a technology for a CCS project. Ultimately SaskPower selected this integrated arrangement as their technology of choice for their Integrated Carbon Capture & Sequestration (ICCS) project at Boundary Dam (Unit #3). Progression of the on-going plant construction is shown in Figure 3 to follow.

The Technology

Figure 2 opposite shows the flowsheet (simplified) of the SaskPower integrated SO_2/CO_2 Capture system in construction above.

Brief Cansolv Technology Description

Fluegas is first sent to the SO_2 absorber and then onto the CO_2 absorber before being returned to the stack with zero SO_2 and only 10% of the CO_2 remaining. The fluegas is first quenched and sub-cooled in a Prescrubber section, which is located in the SO_2 absorber. SO_2 and CO_2 are absorbed from the gas by contact with the Cansolv solvents through sections of structured mass transfer packing in the absorption towers. Lean cool amine is fed to the top of each Absorber Tower.

In each tower, as the absorbents flow down the column counter current to the feed

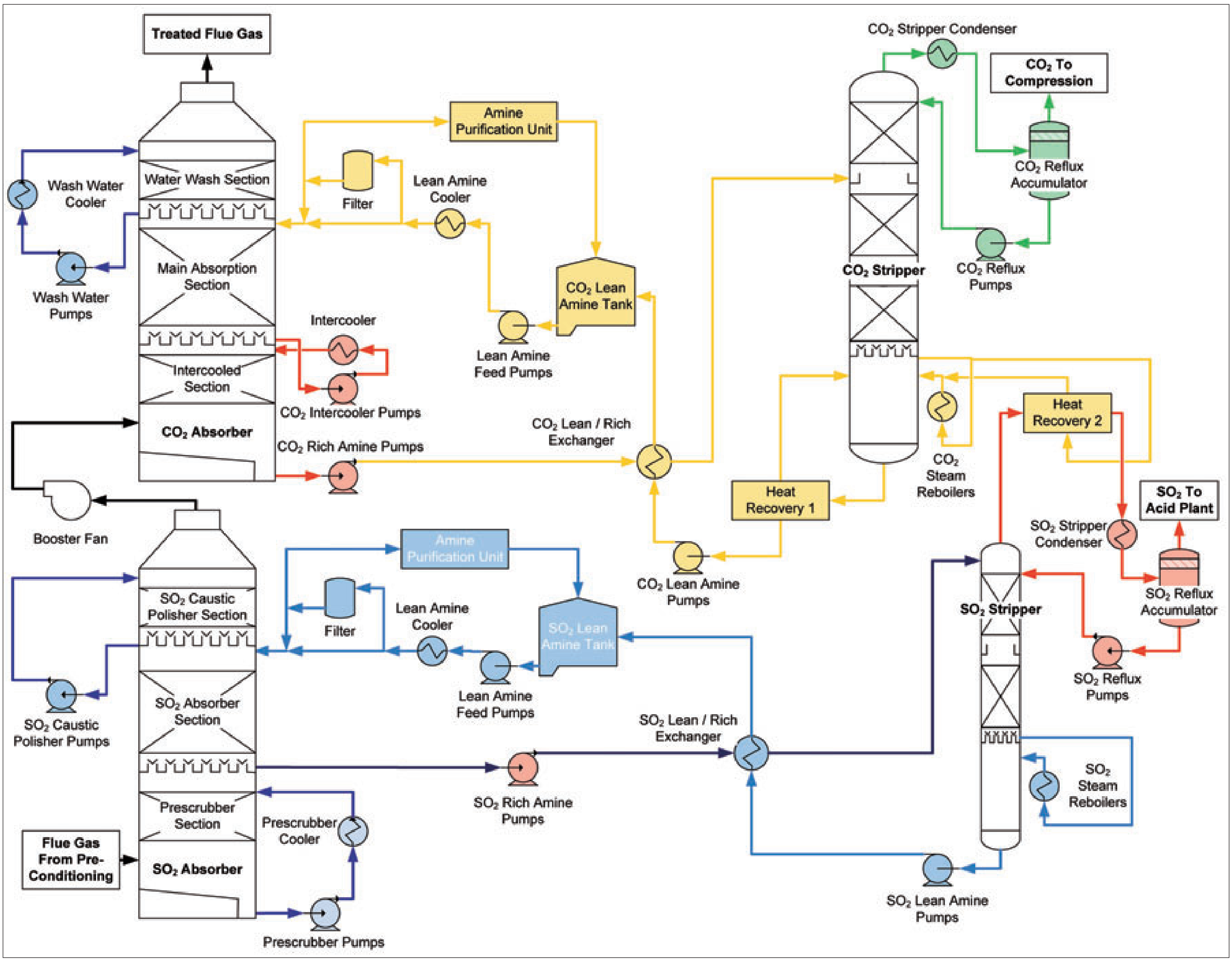


Figure 2 - Flowsheet of the SaskPower integrated SO2/CO2 Capture system

gas, the pollutant is absorbed into the amine. The rich amine collects in the sump of the Absorber Tower and is pumped to the Regeneration Tower (or "Stripper"). Since the absorption of CO2 is an exothermic reaction, interstage cooling is employed mid-tower to remove this heat from the Absorber tower, thus maintaining absorption efficiency.

The rich absorbent is pumped at a constant rate to the Regeneration Tower through a Lean/Rich Heat Exchanger that recovers sensible heat from the lean amine. Equipment known as a Reboiler uses low pressure steam to indirectly generate stripping steam which is injected into the bottom of the column. As the liquid solution flows down the tower, it meets the rising hot steam in sections of mass transfer packing where the heat reverses the absorption reaction and returns the SO2 and CO2 to the gas phase.

In each case, the gaseous product is carried overhead and cooled in the respective Stripper Condensers where most of the steam condenses. Water-saturated product (vapor) and product-saturated condensate are separated in the Stripper Overhead Accumulator and the condensate is returned to the top of the Stripper Tower as reflux. The gaseous product leaves the Stripper Overhead Accumulator and is delivered at positive pressure for downstream handling.

Features

Some of the unique features of the SaskPower Boundary Dam plant are:

Cooling

Efficient cooling equipment upstream of the CANSOLV plant is providing a very cool gas which improves overall performance of the system. Every amine system performs better at cooler temperatures – so it is a tradeoff on the value of cooling the fluegas versus the benefit of the capture performance that must be evaluated on a project-by-project basis. In very hot climates for example, cooling can be extremely expensive and therefore these costs may outweigh the benefit gained by running the capture plant cooler.

Boundary Dam happens to be located in a fairly cool environment -especially in the winter- and is ideally located next to a cool water source. Therefore SaskPower is able to take advantage of a system designed for optimal temperatures for the capture plant. In fact, it gets so cold in the winter season, SaskPower opted to design the system to be housed in a closed and temperature controlled building depicted in Figure 1 as the optimal winterization strategy.

Absorber Design

Since SaskPower selected the Cansolv technology, the SO2 and CO2 scrubbing systems can be designed to be housed in the same structure. As they are sequential; they are essentially designed as one block. This means minimal plot space requirements as well as cost savings, since the design actually allows for the sharing of a common wall between the 2 sections.

Another noteworthy feature is the selected material of construction (MOC). As the absorbers both operate at atmospheric conditions, and are therefore not pressure vessels, significant costs savings are realized by opting for an MOC such as concrete lined with appropriate acid resistant tiling to withstand the wet scrubbing environments.

And finally, in the SaskPower case it was also decided to design the towers as rectangular vessels rather than the typical cylindrical tower design. This enabled the wall sharing described above, but also allowed for a simple design and supply of the mass transfer packing which is installed inside the towers.

Heat Integration

Since SaskPower values their low pressure steam very highly, in this case it was also worth considering optimizing the plant for superior energy consumption. Unique to CANSOLV is the ability to recover energy from one section (SO2 scrubbing) and use it in the next (CO2 capture). This is done using special equipment (Mechanical Vapor Recompressors or MVR) to convert otherwise wasted energy into high value steam. This is a trade-off of some investment in equipment and some electrical energy in exchange for a reduction in LP steam consumption.

This is a case-by-case evaluation that requires careful consideration. Ultimately, the value decision by SaskPower was to opt for this line-up. The result is leading class energy consumption, and to a much smaller extent some savings in peripheral equipment sizes. Since this line-up converts liquid streams into energy, some of the resulting streams in the system to be treated are effectively smaller.

More than carbon capture

Since by definition Boundary Dam is a "carbon capture" project, one may ask why the need to also remove SO2. The answer can be brief. Essentially SO2 that may be present in the fluegas entering into the CO2 capture absorber would be absorbed into the CO2 capture solvent preferentially. This is a two-fold problem: 1) this takes up room in the solvent that is supposed to be absorbing CO2 and 2) since the bond of the SO2 in the solvent can withstand the "steam stripping" in the CO2 regenerator – additional equipment would be required to then remove the SO2 from the solvent.

Economically, and operationally, it makes sense to remove the SO2 before it gets to the CO2 absorber.

Figure 3 - The Cansolv CO2 & SO2 capture plant at SaskPower's Boundary Dam power plant, currently under construction, will start to capture CO2 by the end of 2013

In a project such as Boundary Dam where SO2 and CO2 removal is required for a CCS project, there are several options available to accomplish the goals. Specifically when it comes to SO2 removal, a common approach would be to consider a standard Fluegas Desulfurization (FGD) scheme employed nearly worldwide for power applications. These are "once-through" alkali scrubbing units. This means non-regenerable systems that use a reagent such as caustic, lime, limestone or other to scrub out the SO2.

For large scale power applications wet limestone scrubbing is one of the most commonly used systems. One of the advantages CANSOLV offers in this project is that CANSOLV SO2 scrubbing delivers a pure stream of SO2 product to the client, instead of a waste product such as gypsum. These waste products often require disposal of some sort and therefore related legacy disposal and transportation costs and obligations. In the case of SaskPower, the pure SO2 product is to be converted on-site into sulfuric acid (H2SO4) - which is a saleable by-product.

In the particular case of SaskPower due to its location this is a twofold benefit:

1) The local fertilizer industry (among others) suggests that the H2SO4 from CANSOLV would be a welcomed product rather than a waste to handle (i.e. low quality gypsum for disposal)

2) As limestone is not native to Saskatchewan and would have to be imported from abroad, transportation and legacy environmental impacts related thereto are reduced, along with continual reagent purchase costs.

Conclusion

As a demonstration project, SaskPower is taking the very involved and complex measures required to be able to fully evaluate and appreciate the intricacies of CCS. This information will be used to make the value decision going forward about whether or not CCS will be a viable option for Saskatchewan to be able to de-carbonize and continue using its abundant local natural coal resources to meet a significant portion of the provinces growing electricity needs.

While several other similar demonstration projects around the globe are also progressing rapidly - and learnings from all of these will be required in order to move CCS forward in the future - the SaskPower Boundary Dam unit 3 Integrated Carbon Capture and Sequestration project is leading the pack and CTI is privileged to be a part of this pioneer project watched by the world.

More information

www.cansolv.com
www.saskpowercarboncapture.com

University of Regina: pioneering research

The International Test Center for CO2 Capture has been developing technologies to make carbon capture work since 2001. It's latest innovation is a catalyst-aided process that could virtually eliminate the energy penalty for post-combustion CO2 capture.

Most people, when they think of carbon capture and storage (CCS) activities in Saskatchewan, think immediately of the Weyburn Project (formally known as the IEA GHG Weyburn-Midale CO2 Monitoring and Storage Project). This is probably the world's flagship project when it comes to CCS, but it really is only one half of the CCS picture – the storage half. However, in Saskatchewan, because CCS is vital to our social and economic future, we have more than just Weyburn to offer.

For more than 20 years, researchers in the Faculty of Engineering and Applied Science at the University of Regina have been studying and developing technologies for the other half of the CCS equation – carbon capture. These researchers are world leaders in carbon capture research and development (R&D), and their focus is firmly on developing technologies that will work not just for Saskatchewan, but for the world at large.

As part of their efforts, the University of Regina carbon capture research group established the International Test Centre for CO2 Capture (ITC) in 2001. This $25+ million research centre features two multi-million dollar pilot plants for post-combustion capture research and demonstration, and it includes one of North America's most advanced laboratory facilities with an array of analytical equipment that remains state-of-the art more than a decade later.

There are a number of unique features about the ITC as a research centre for CO2 capture. In the first place, ITC's research, development, and demonstration (RD&D) program is among the most comprehensive in the world. Studies include all aspects of the CO2 capture process, including corrosion prevention and management, amine degradation and reclamation, process control and modeling, and even artificial intelligence applications for monitoring and control of post-combustion capture (PCC) plants. The unique array of analytical equipment allows detailed study of the molecular structures of amines and their degradation products, along with characterization of the types of corrosion occurring in the system. The researchers can also fully examine the kinetics and mass transfer and other behaviours of amines and catalysts.

The pilot plants and other facilities are also technology neutral, meaning they can be used not just for development and testing of in-house technologies, but can also be used to provide amine and plant operation studies for external clients, and a major part of the ITC's operations involves providing analytical services.

Also, ITC is the only CCS research facility of its caliber associated with a public institution of higher learning. Consequently, while much of the research is patented and protected, a lot is also published openly. In addition, one of the most valuable services offered is training. ITC is the only facility in the world where engineers and scientist can be trained in the complete operations of large-scale CO2 capture operations. As such, much of the work is conducted by young researchers in training. This provides industries around the world with an excellent source of highly qualified personnel to help them make decisions about the application of CCS in their operations and design potential CCS projects.

Incidentally, process design is another service offered by the ITC. The group has provided Front-End Engineering Design analyses for numerous organizations around the world.

The ITC's primary focus has been on developing post-combustion capture (PCC) with amines, and the researchers chose to focus on this area for a number of reasons.

First, amine solvent applications have been used to treat fossil fuel gas streams for decades, so the technology is already well established and understood. This meant that the focus could be placed more on scaling up an established technology rather than purely on invention, so industrial-scale CO2 capture could be brought online much faster.

This does not mean, however, that the work done at ITC is not without novelty or invention. "What we're really doing here is reinventing an existing technology to make it work economically on large scales and in a new application. It's a bit like redesigning technologies that work well on earth to work even better in space – it's a whole new environment," explains Dr. Paitoon Tontiwachwuthikul, one of the early pioneers of PCC and a co-founder of the ITC.

The novelty this group has brought to the field of CCS is extensive. The group has published hundreds of journal papers and dozens of technical reports. They've trained dozens of young engineers and researchers, but most importantly, they've designed some of the world's most efficient, effective, and economically viable CCS technologies available today. They have developed an entire line of novel amine solvents that consistently out-perform conventional and competitors' solvents. They've invented process designs that dramatically reduce the energy required for carbon capture plant operations, which is one of the key stumbling blocks for commercial implementation of CCS. As Dr. Raphael Idem, Chief Researcher at ITC, points out, "Carbon capture is by far the most expensive component of CCS. CCS will only be economic when an energy efficient system for post-combustion capture is proven on a commercial scale."

Re-inventing post combustion capture with amines - Dr. Paitoon Tontiwachwuthikul, one of the early pioneers of PCC and a co-founder of the ITC

At present, there are tens of thousands of conventional fossil fuel combustion facilities operating many of the world's most vital industries. Many of these, such as coal-fired power plants, have extremely long life spans (as many as 50 years) and are so cost-effective compared to alternative technologies that it would be impossible for most economies to suddenly shift to alternative, clean energy processes without incurring unsustainable economic penalties. In other words, the underpinning of the global economy is fossil fuels, and it will remain so for decades to come. PCC, because it can be used to retrofit conventional fossil fuel combustion facilities for carbon capture, represents the best hope of making dramatic, large-scale reductions in industrial CO2 emissions without significantly increasing costs of energy and manufactured goods or disrupting the global economy.

This is another reason Saskatchewan is playing a critical role in global CCS development. Saskatchewan's economy is one of those that depend heavily on fossil fuels. Petroleum and mining make up about 13 per cent

of Saskatchewan's GDP. This is the largest contributor to the provincial economy next to the service sector, which, itself, depends heavily on the province's energy and fossil fuel industries.

Saskatchewan also has, perhaps, the world's largest per capita CO_2 emissions (about 73 tonnes per person – twenty more than Qatar, the nation with the highest per capita emissions). This, of course, is a deceiving statistic, since Saskatchewan's actual CO_2 emissions are only about 75 megatonnes per year, which is small compared to the actual emissions of many jurisdictions with very low per capita emissions. Consider Iran, whose per capita emissions are around 8 tonnes per person but total emissions are a whopping 574 megatonnes.

More significantly, about 70 per cent of Saskatchewan's electricity is generated via fossil fuel combustion, the vast majority of which is coal-fired power.

While this would be problematic for any jurisdiction looking to reduce emissions, it is actually far more problematic for Saskatchewan than it is for most other places with a high proportion of fossil fuel-based electricity generation. While other jurisdictions in Canada and around the world also have a large portion of their electricity generated using coal-fired power, it is not for lack of viable alternatives.

Many places, like Ontario, for example, are electing to simply phase out their coal-fired power. They can do this because their climate, geography, and population demographics are far more conducive to making this switch.

Take, for example, nuclear power. Ontario has a very large population, by comparison to Saskatchewan. So, for that matter, does Alberta, the other province with a very large portion of its electricity coming from fossil fuels. Nuclear power, however, is a very large-scale technology. It is really only economically and technically viable when used in areas with high electricity demand (i.e., those that are more densely populated). A single, small-scale nuclear plant would essentially produce more electricity than Saskatchewan can use. On the surface, this might appear appealing – we could sell the surplus to our neighbours.

But there's a catch – actually, two catches.

In the first place, the province's entire electricity production would essentially be coming from a single source – never a good idea in terms of energy security. This is particularly problematic, since, next to the northern territories, Saskatchewan is Canada's coldest province, experiencing more days below -18°C per year than any other province. Lengthy electricity outages in the winter are simply not an option. The other catch – Saskatchewan's entire electricity transportation infrastructure would need to be replaced, since it is not designed to handle the output of a nuclear plant.

So, if nuclear won't work, what about hydroelectricity? Once again, Saskatchewan is at a distinct disadvantage. While the other provinces, as well as the northern territories, have ample water resources to make hydroelectric power a viable primary energy source, Saskatchewan has a semi-arid climate with few major lakes and rivers, at least not in the most densely populated areas. So hydro is only a supplemental option.

Of course, Saskatchewan does have plenty of wind, but since the wind doesn't always blow when electricity demand is peaking and electricity storage technology hasn't reached the point where this doesn't matter, wind, too, is only viable as a supplemental rather than primary electricity source in Saskatchewan.

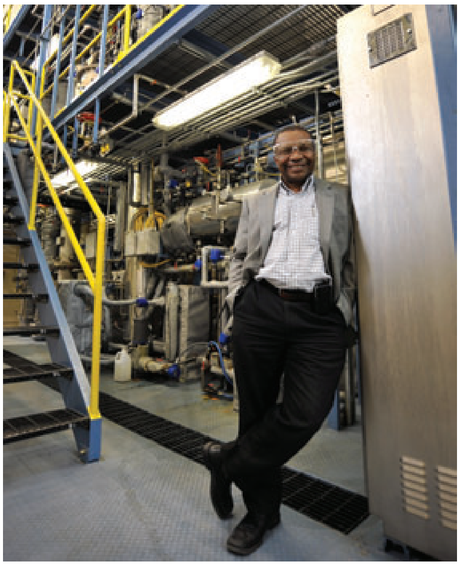
While Saskatchewan does have a very good agricultural base for bio-renewable energy options, these technologies are in their infancy, and it will be decades before they are ready to meet current energy demand. The world simply cannot afford to keep up unmitigated use of fossil fuels at its ever-expanding rate while waiting for biofuels to become a viable primary energy source.

For Saskatchewan, at least for now, fossil fuel-generated power is the only viable option, which means that carbon capture is an essential technology for this province. As a result, researchers at the University of Regina and the ITC are focused on making carbon capture work.

Latest research

But, that's not their only focus. In fact, these researchers are taking a uniquely long view to the problem of clean energy and greenhouse gas emissions reduction. In addition to their comprehensive post-combustion capture program, they also have R&D programs in biofuels and other alternative energy options.

Of particular note is the work of Dr. Raphael Idem, Dr. Hussameldin Ibrahim, and Dr. Ataullah Khan on catalyst-based hydrogen production. This team has designed an extremely promising novel catalyst that allows hydrogen production to be both feed flexible and process flexible. In other words, a single catalyst can be used to switch between feedstocks without disrupting plant operations. Even better, the catalyst can convert even unprocessed feedstocks, like raw ethanol and low-grade natural gas, into hydrogen. This means that many waste products, such as glycerol, fusel oils, and biogas, can become value-added fuel feedstocks.



Dr. Raphael Idem, Chief Researcher at ITC, and his team have developed catalysts for hydrogen production and energy efficient post-combustion carbon capture

The process also incorporates capture, recycling, and storage of CO_2, making it CO_2 neutral when used with fossil fuels and a CO_2 sink when used with biofuels.

In an interesting twist, the researchers' most recent catalyst research suggests that they might just have found the magic bullet to make post-combustion capture not just economically viable, but perhaps even value added.

The group has very recently developed an entirely new catalyst-aided process that dramatically increases the efficiency of the post-combustion capture process. The new catalyst enables the capture process to operate using hot water instead of steam, which virtually eliminates the energy penalty associated with post-combustion capture.

"With this technology," explains Idem, "we can make a business case for carbon capture based on added value rather than regulatory requirements." In other words, carbon capture plants can be operated without substantially affecting the efficiency of the original process, and the captured CO_2 can be sold for use in enhanced oil recovery (EOR) operations, making this an ideal means of obtaining CO_2 for EOR.

This technology has been described by many in the CCS industry as a game-changing breakthrough, and it represents the most recent innovation in CCS to come out of Saskatchewan, which has been a long-established pioneer in CCS development.

More information

www.uregina.ca
www.co2-research.ca

Storage at Weyburn safe says study

Third-party research has confirmed that the carbon dioxide Cenovus Energy uses for enhanced oil recovery at its Weyburn operation is not linked to CO2 concentrations in the soil at a nearby property.

"These results provide complete assurance to landowners and the public that the CO2 we're injecting about 1.5 kilometres below the ground is staying put and that our Weyburn operation is safe," said Brad Small, Cenovus Vice-President, Oil & Natural Gas, Saskatchewan.

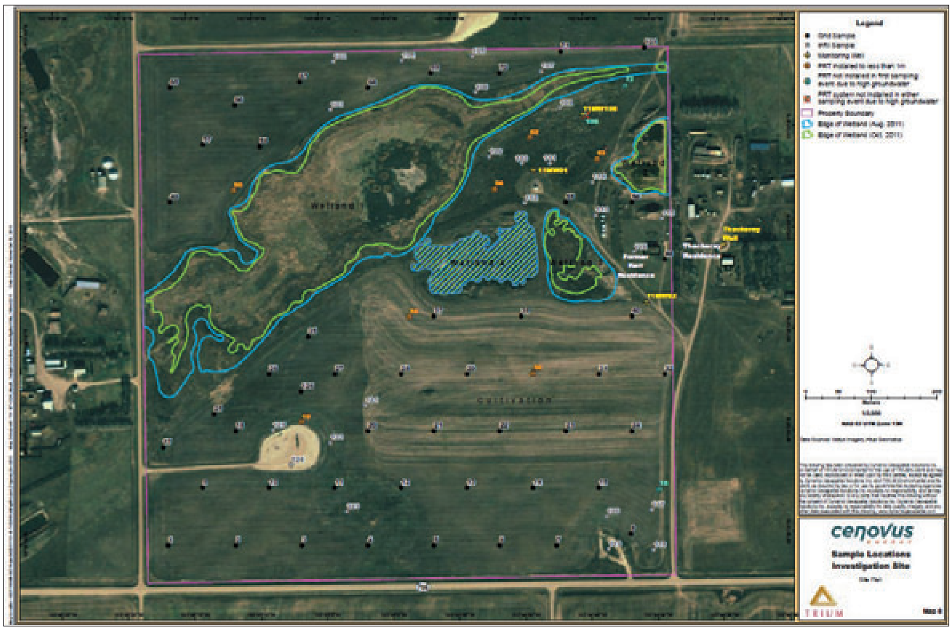
Cenovus, which operates the Weyburn Unit on behalf of 23 other partners, made a commitment to the Saskatchewan Ministry of Energy and Resources to evaluate whether CO2 in the soil and other reported issues at a nearby property were a result of its operations. Several third-party specialists were contracted to conduct a site assessment.

"Our findings indicate that there is absolutely no way CO2 in the soil at the property in question originated from Cenovus's operation in Weyburn," said Court Sandau, PhD in analytical chemistry, founder of ChemistryMatters and lead scientist for the site assessment. "Using isotope dating, we can differentiate between 'young' and 'old' carbon samples. The CO2 that Cenovus injects comes from coal deposits, which were formed millions of years ago. Our findings assert that the CO2 present at the property was formed recently and is attributed to natural soil respiration processes."

Findings of the assessment confirm:

- there is no presence of CO2 from Cenovus's Weyburn operation in either the soil or wetlands of the property;
- there are no detectable hydrocarbons present in the surface water at the property; and
- there are no integrity issues with the Cenovus-operated wells and infrastructure located on the property.

The scope of the assessment included the evaluation of gas concentrations in the soil at both the property and a control site; characterization of the CO2 that Cenovus injects and the CO2 found in the soil; surface and groundwater testing, and integrity inspection of the oilfield infrastructure in the area. The full reports are available at www.cenovus.com.



Updated sampling grid for investigation site based on a statistical analysis sampling plan accounting for presence of water bodies and infrastructure (Source: ©Cenovus Energy Nov 2011 "Summary of Investigation")

"We did not detect any hydrocarbons when conducting surface water sampling," said Sandau. "Cyanobacteria and phytoplankton were detected, which are common to relatively stagnant water bodies in southern Saskatchewan and are known to cause a 'sheen' on water surfaces, similar to what was initially reported on the water body."

Cenovus also added a frog habitat and wetland evaluation after northern leopard frogs were found in the study area.

"Frogs are sensitive to low levels of contamination. Their presence in the area is a strong indicator that a healthy ecosystem is present," said Sandau.

CO2 has been injected at the Weyburn Unit since 2000. When CO2 contacts oil at high pressure, it makes the oil thinner and causes it to swell, making it easier for the oil to flow to producing wells. The CO2 that is pumped out with the oil is then recycled.

Weyburn is one of Canada's largest enhanced oil recovery operations and the site of the largest geological greenhouse gas (GHG) storage project in the world. There are currently more than 17 million tonnes of CO2 stored at the Weyburn site. Scientists from 30 countries working under the International Energy Agency GHG Weyburn-Midale CO2 Monitoring & Storage research project, an international program led by the Petroleum Technology Research Centre, have been studying the project for a decade. Their past research indicates that the CO2 is remaining underground.

More information

www.cenovus.com
www.ptrc.ca

CCS legal and policy – UK competition

At long last the process of deciding which of GB's incipient CCS demonstration projects will receive state support has recommenced in earnest. The new process contrasts sharply with its recently departed predecessor and offers much cause for optimism.

Following an astute amount of well designed consultation with industry, DECC launched its CCS Commercialisation Programme (the Programme) around the beginning of April. Through the consultation, the proposed procurement process was communicated to the various stakeholders and their views actively sought. This should have engendered industry buy-in to the Programme and appears to have yielded a process for project selection which gives DECC the best possible chance of finally kick-starting the development of a viable CCS industry in the UK.

One of the key reasons that the first CCS demonstration competition had the tortured life that it did was that the policy drivers at its inception were ill-conceived. The status of Government policy and its effect on the new competition has therefore been of much interest to those watching the competition process develop. This interest was well directed and the Programme that has emerged tells a lot about how policy has changed in the five years or so since the first project was launched.

The overarching policy aim that comes through most strongly now is that the Programme is not simply to procure a few projects, but is intended to create the basis of a CCS industry in the UK. This may seem an obvious and unnecessary statement to make, but its explicit pronouncement, and the increment of confidence it gives to those considering investing, is very important. Cynical observers may take a suspicious view with regard to the sincerity with which this particular policy is espoused; nevertheless it resonates reassuringly through many of the foundation stones of the Programme.

By way of example, the central stated aim of the Programme is to achieve the CCS Commercialisation Outcome. The 'Outcome' is rapidly achieving the status of a mantra for the faithful and I therefore repeat it here in full:

"As a result of the intervention, private sector electricity companies can take investment decisions to build CCS equipped fossil fuel power stations, in the early 2020s, without Government capital subsidy, at an agreed CfD Strike Price that is competitive with the strike prices for other low carbon generation technologies"

The statement clearly and undeniably looks to the future and the role of CCS industry as a means of allowing ongoing fossil-fuelled power generation within a diverse, low-carbon, energy mix. This appears to support the claim that industry development is central to the Programme and the Outcome includes other aspects with the same message: the need for a CCS industry, and the way it will develop, is now primarily driven by a need for energy security, not simply environmental imperatives, and there is a recognition that this must be paid for, on a sustainable basis, by energy consumers as part of the cost of the energy that they consume.

Environmentalist purists may bemoan this alteration in the source of impetus for CCS development and it may indeed lead to some perverse outcomes; reductions in CO2 emissions from industrial emitters, for example, is unlikely to receive the proportion of attention it deserves. Nevertheless, a pragmatic advocate of CCS is likely to view the linking of the industry's development to energy security as a strong factor in increasing the likelihood of it attracting investment.

Other key messages from the consultation process are encouraging for those who want to believe that there is a genuine policy to see CCS flourish in the UK. The frustrations that have bedevilled those trying to obtain state support for shared CCS infrastructure and clustered capture (and storage) projects, via procurement processes that ostensibly supported such outcomes but in practical terms made them impossible to achieve, have been addressed in the Programme by the acceptance of part-chain proposals which will be enabled, by a sufficiently flexible and well designed, competition process, to amalgamate into cluster projects as the process progresses.

The potential of EOR to bring an additional revenue stream to the CCS commercial equation, and the importance this might have in supporting the development of CCS has also been explicitly recognised. Similarly, there is early cognisance that there are limitations on the amount of finance that can be provided by Government and a concomitant desire to create a project selection process that encourages the investment of private finance into the projects in order to bolster the funding from the national accounts.

Calum Hughes, Yellow Wood Energy

So there is much to be positive about as we embark on this latest exercise, but those who read this column regularly will know that it rarely contains a wholly roseate viewpoint. And this edition is no different, there are some concerning issues with the potential to scupper the Programme: the following three are probably the most significant.

Firstly, and most obviously, is the current uncertainty with respect to the detail of the proposed Contract for Difference (CfD) as an instrument of long term support for the costs associated with CCS. At the moment this uncertainty makes it difficult to assess whether the proposed CfD is fundamentally suited for application to CCS, but, from what we do know, it does seem that its designers are faced with two potentially significant difficulties: fuel price risk and system demand (or usage) risk.

The former of these hinges upon the problem of establishing a CfD strike price (or strike price mechanism) that allows for the vagaries of fossil fuel price whilst the latter is based the problem of the amortisation of fixed development and operational costs over a variable, and highly uncertain, number of zero-carbon megawatt-hours exported to the grid. It is certainly possible for these issues to be satisfactorily addressed in the final CfD design, but this will be difficult and may require concessions that Government is not willing to make.

The question in potential developers' minds will be whether it will be clear which way things will go in time to make final investment decisions with regard to CCS demonstration projects. What is currently clear is that the timings of the electricity market reform process (of which the CfD is a component part) and the Programme seem woefully out of sync; with the EMR lagging

considerably.

The second concern is with the Outcome. The Outcome's central purpose is to achieve a reduction in the cost of the next generation of CCS projects and an increase in confidence in both the accuracy of the estimate of those costs and the technical feasibility and operability of CCS. It is very likely, of course, that the projects supported via the Programme will achieve these aims to some degree; every project brings learning and experience. But the Outcome requires that this learning and experience be of a level sufficient to meet a quantified goal, viz: to enable future projects to be commercially viable without state capital subsidy.

This seems a peculiar thing to ask of a project developer. Ask it to meet a technical specification, yes, to bring a project in on time and in budget, certainly, but to ensure that the economics of the projects to follow are within certain parameters? It is difficult to see how a project developer could achieve this, or, within the context of its current project, why it would want to. For example, driving down the cost of the equipment one is procuring today is one thing, but how would one require one's supplier to sell to its next customer at some fixed percentage less than it was currently selling? The aim of the Outcome is a laudable aspiration but it seems unwise to make it the yardstick by which the demonstration projects will be judged to have succeeded or failed.

The final concern is the least easily perceived and perhaps the most threatening. It is whether the Government and the various industry stakeholders value CCS highly enough to share between them the risks involved with getting the first projects, and therefore the industry, off the ground. With regard to the Government's aims, the current level of the carbon price demonstrates that carbon emission driven climate change remains a societal cost to which the ETS does not ascribe a high enough value to meet the UK's emission reduction targets; direct support for CCS has the potential to address this problem.

From potential investors' and developers' points of view, CCS (and, in the context of the Programme, low-carbon fossil-fuelled electricity generation especially) has the potential to be a profitable industry into which to develop but there remains many uncertainties and potential bear traps. The question is then, whether the value of CCS to these parties, in aggregate, is sufficient to persuade them to collectively shoulder the risks and move forward and whether, in seeking to attain the best deal, those risks can be divided up in a mutually agreeable manner. Whether they can or not will only become apparent once serious contract negotiations are underway and by that time a lot more money will have been spent.

These issues are disquieting but the well-considered fashion in which the Programme has been developed to date provides good grounds for hope that, in the final analysis, they will prove surmountable.

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UK CCS competition - a new beginning

The UK has set out its new long term CCS plans following on from the cancelled CCS demonstration project competition.

The UK's recently appointed Energy and Climate Change Secretary Edward Davey has launched a new CCS competition to receive the £1 billion capital funding which went unclaimed after the abandonment of the first competition, launched in 2007.

The competition, which is to be known as the 'CCS Commercialisation Programme', is again designed, 'to support practical experience in the design, construction and operation of commercial scale CCS.' In order to qualify for the competition, projects must:

- be CCS Full Chain, or part chain capable of demonstrating the prospect of being part of a Full Chain Project in the future;
- have the power plant and capture facility located in GB and the storage site located offshore;
- be operational by 2016-2020, though earlier is desirable;
- abate CO2 at commercial scale (or be a substantive step toward that objective) whilst meeting all relevant environmental requirements; and
- be an electricity generator, or an Industrial [CO2] Emitter where it is part of a Cluster Project.

The Department of Energy and Climate Change (DECC) at the same time published a UK CCS Roadmap and awarded £125m for Research and Development, including a new £13m UK CCS Research Centre.

"What we are looking to achieve, in partnership with industry, is a new world-leading CCS industry, rather than just simply projects in isolation," said Ed Davey, "an industry that can compete with other low-carbon sources to ensure security and diversity of our electricity supply, an industry that can make our energy intensive industries cleaner and an industry that can bring jobs and wealth to our shores. The CCS industry could be worth £6.5bn a year to the UK economy by late next decade as we export UK expertise and products."

The UK Carbon Capture and Storage Association (CCSA) also gave its support: "Today's announcement sets out one of the most comprehensive support packages for CCS in the world, sending a positive signal to the CCS industry, who are ready and waiting to respond," commented Jeff Chapman, CEO of the CCSA. "Indeed, the industry is already responding - in the last fortnight alone, plans for a new commercial-scale CCS project were announced and another proposal also announced major inward investment from an international company bringing to seven the number of proposed large scale projects in the UK."

UK National Audit Office (NAO) conclusions on the first UK CCS competition

The NAO report concluded that the competition had been a high risk and challenging undertaking launched with insufficient planning and recognition of the commercial risks.

The competition was launched in 2007 by the then Department for Business, Enterprise and Regulatory Reform. It was cancelled four years later by the Department of Energy and Climate Change (DECC) on the grounds of protecting value for money and because the project could not be funded within the £1 billion budget agreed at the 2010 Spending Review. The results of engineering and design studies completed by bidders, upon which the Government spent £40 million (63 per cent of the £64 million it spent in total on the competition), may help to reduce the costs of future carbon capture and storage projects. The cost of the competition was relatively small compared to the investment required to develop CCS at commercial scale and the competition has increased the Department's experience in this field and understanding of project costs.

DECC now plans to pursue other carbon capture and storage projects using the £1 billion capital fund. The NAO has made recommendations for the Department to address in its future programme.

The former Department for Business, Enterprise and Regulatory Reform had wanted industry to take up a commercial contract for a large and potentially costly developmental project, even though there was considerable uncertainty over its design and costs.

Neither DECC nor its predecessor engaged sufficiently early with the commercial risk involved. During the competition, DECC's decisions to continue were not informed by detailed consideration of the probability of reaching acceptable contract terms and the time lost should the competition not succeed. The inability to agree mutually acceptable terms with all members of the consortium contributed to DECC's decision to cancel the competition. For its new programme, the Department needs to understand fully its commercial proposition to industry.

Lack of clarity over government finance for the project delayed the early stages of the competition. When a capital budget was decided in October 2010, there was no agreement on government funding for operational costs. For its new programme, the Department and Treasury should be clear on the public investment available and establish any affordability constraint.

Amyas Morse, head of the National Audit Office, said:

"In the context of value for money, developing new technologies is an inherently risky undertaking. Taking calculated risks is perfectly acceptable if those risks are managed effectively; but in this case DECC, and its predecessor, took too long to get to grips with the significant technical, commercial and regulatory risks involved.

"Four years down the road, commercial scale carbon capture and storage technology has still to be developed. The Department must learn the lessons of the failure of this project if further time is not to be lost, and value for money achieved on future projects."

Support through the EMR

The CCS competition will help to get a project off the ground, but continuing support will be necessary to make CCS sustainable as part of normal UK power generation.The Electricity Market Reform (EMR) programme gives developers of CCS power projects more certainty, via a set of incentives. These include:

- the prospect of long-term contracts that reflect the value of low-carbon generation to the electricity market;
- financial support for early stage CCS projects that will help overcome the additional demonstration risks associated with these projects whilst ensuring that this support remains

affordable for consumers;
- an Emission Performance Standard (EPS) set at a level to limit the emissions of new unabated coal fired power stations, but with exemptions for plants that install CCS;
- a Carbon Price Floor that, together with the EU-Emissions Trading System, will penalise the combustion of fossil fuels. Again there are exemptions for CCS;
- a requirement for all new fossil fuel power stations to be Carbon Capture Ready, to ensure that newly constructed unabated fossil fuel power stations are able to fit CCS.

CCS Research Centre

The Engineering and Physical Sciences Research Council (EPSRC) and DECC have announced a £13 million investment to establish a UK CCS Research Centre.

EPSRC will invest £10 million over a five-year period, with funding of £3 million from DECC to establish new capital facilities that will support innovative research.

The new Centre, based at the University of Edinburgh, will be a virtual network where academics, industry, regulators and others in the sector can collaborate on analysing problems and undertaking research. A key focus will be to maximise the contribution of CCS to a low-carbon energy system for the UK.

Other institutions involved in the centre are the Universities of Cambridge, Cranfield, Durham, Leeds, Newcastle, Nottingham and Imperial College London, the Plymouth Marine Laboratory and the British Geological Survey

The new capture research facilities will allow UK scientists and engineers to work with industrial partners to develop improved capture technologies. The facilities include:
- pilot scale advanced testing facilities in Yorkshire, with a 1 tonne CO2 per day amine capture facility
- a mobile testing unit to allow a range of tests to be conducted on real power station flue gases
- advanced oxyfuel fluidised bed and chemical looping pilot facilities.The Centre's first goal will be to identify further research needed to accelerate CCS deployment.

An integrated pipeline network

UK National Grid believes it will be far more cost effective to provide single, large scale pipelines, into which several carbon emitters in a region can connect.

This 'cluster' or 'gateway' approach could deliver the UK Government's aspiration of cost competitive power generation with CCS, decarbonise the UK's electricity generation and industrial sectors, and provide a lasting legacy from this phase of the development of CCS.

National Grid is involved in a number of projects around the UK where it is demonstrating both its commitment to the cluster approach and its expertise in designing, constructing and operating multi-user pipeline systems.

On Humberside, through its Humber Gateway development, it is working with: 2Co Energy on the Don Valley Power Project near Doncaster; Alstom, Drax and BOC Linde on the White Rose Project near Selby; and C.Gen Power on its North Killingholme Power Project.

At Grangemouth, west of Edinburgh, it is working with Seattle-based Summit Power and Petrofac on the Caledonia Clean Energy Project.

And on Teesside, it is part of a consortium alongside BOC, International Power, Fairfield Energy, Premier Oil and Progressive Energy developing the Teesside Low Carbon Project.

Alongside the carbon dioxide transportation solutions, National Grid is also developing a saline formation storage site in the southern North Sea, known as 5/42, which it intends to offer into the DECC competition process and make available to emitters. National Grid believes the site offers secure and economic long term storage for CCS projects close to the largest source of emitters in the UK.

UK study on CCS cost reduction

DECC has commissioned a report to analyse the scope for cost reduction by fuel/technology and components for CCS.

It is expected that the study will give projections for a range of outcomes, illustrating the uncertainty in both initial cost estimates and cost trajectory. However it is likely to indicate the potential for a downward trend in costs.

The analysis will be compiled from the bottom up, attempting to identify the cost drivers acting on the main components for each of the four main capture technologies, pipelines and the two main storage options. While the report will identify various technical developments it is difficult to translate this into cost changes as more efficient or better performing equipment does not always come at a lower cost. The numbers provided in the report are the best estimates possible based on available data.

Some examples of areas the report is likely to examine are:
- compressor advances – energy penalty benefits for all options
- air separation advances – energy penalty benefits for oxy combustion and to a lesser extent IGCC
- improved solvents and sorbents – resulting in smaller absorbers, lower energy penalties for post combustion
- gas recirculation for post combustion gas – reduced absorber size and energy penalties
- economies in scale in absorbers – for post combustion
- improvements in construction logistics from learning and advanced simulations – for all options
- process optimisation for all technology routes
- reduced design margins for all systems

CCS Cost Reduction Task Force

DECC has asked the Carbon Capture and Storage Association to establish an industry-led CCS Cost Reduction Task Force to work alongside the Office of Carbon Capture and Storage to set out a path and action plan to reduce the costs of CCS.

The objective of the Task Force is to advise Government and industry on reducing the unit cost of CCS so that it can compete with other low carbon technologies in the electricity market by the early 2020s.

The Task Force will:
- build on work undertaken for DECC to identify potential reductions in the cost of CCS; the scale of those reductions; and the actions required to deliver those reductions;
- seek to gain a commitment from Industry on initiatives to reduce cost and develop advice setting out the steps industry and Government could take to develop the most promising technologies and establish the right market framework and incentives to encourage industry to invest; and
- produce a report to the CCS Development Forum setting out its findings and recommendations for action by Government and industry.

The work of the Task Force will help to shape the future of the Government's CCS Programme and the Roadmap will be updated to reflect the findings and recommendations of the Task Force.

More information

www.decc.gov.uk
www.nao.org.uk
www.ukccsrc.ac.uk
www.ccsassociation.org
www.nationalgrid.com

Global CCS Institute submissions to UNFCCC

The Global CCS Institute is an accredited observer to the United Nations Framework Convention on Climate Change (UNFCCC), and recently made two submissions to the UNFCCC Secretariat on CCS related matters.

The first submission responds to Draft Decision -/CMP.7 (paragraphs 4 to 6) and further consideration by the Subsidiary Body for Scientific and Technological Advice (SBSTA) on the eligibility of transboundary CCS projects in the Clean Development Mechanism (CDM), and the establishment of a global reserve of certified emission reduction (CER) units for CCS projects in the CDM. This submission is a complementary document to the Institute's February 2011 submission on the limited range of outstanding CCS issues in the CDM as identified by SBSTA.

The second submission responds to decisions arising from FCCC/AWGLCA/2011/CP.17 [paragraphs 79 to 86] and deliberations of the Ad-hoc Working Group on Long-term Collaborative Action under the Convention (AWG-LCA) on the future role and mitigation potential of New Market Based Mechanisms (NMBMs). New market based mechanisms are economic instruments that can help enhance the cost-effectiveness of actions in both developed and developing countries to deliver real, permanent, additional and verified mitigation outcomes. They can also greatly assist developed countries to meet part of their mitigation targets or commitments under the Convention.

Outstanding CCS issues in the CDM

In its February 2011 submission, the Institute:
- notes that the ultimate responsibility for complying with and meeting the commitments of the UNFCCC ultimately rests with governments, and not with the legal private entities;
- considers that to every extent possible, the sufficiency of applying existing CDM modalities and procedures (Decision 3/CMP.1) should be tested;
- considers it to be in all CDM stakeholder interests to be satisfied with the rules of inclusion for CCS under CDM (and potentially other UNFCCC mechanisms);
- believes that CCS can be readily accommodated within the CDM (ie. all issues raised in Paragraph 2 and 3 of Decision -/CMP.6 addressed) on the basis of already established technical and scientific data and analysis, methods and expert advice;
- recommends that a one-size-fits-all approach be avoided where possible;
- views that where appropriate, a fit-for-purpose approach can sufficiently provide for: accurate; conservative, relevant, credible; reliable; complete; and verifiable data monitoring plans and measurement methodologies;
- acknowledges a large number of published peer reviewed expert reports that either contain approaches and recommendations to address and/or redress the limited number of issues contained in Decision -/CMP.6; and
- views that many of these issues can be readily addressed over the short term; and managed through either a policy oriented approach (such as best practice guidelines contained in the modalities and procedures), or within a host country's legal arrangements.

CCS in the CDM

The Institute considers that enabling transboundary CCS projects in the CDM should be given effect as soon as possible through the development of an appropriate suite of modalities and procedures (M&Ps). In the case of CDM, eligible transboundary CCS projects would necessarily involve the capture of CO2 in a developing country, for storage in either an Annex I and/or another developing country.

In terms of possible institutional procedures to guide the inclusion of transboundary CCS projects in the CDM, the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (Chapter 5, CO2 Transport, Injection and Geological Storage), which were formally adopted at COP 17 for the second commitment period, provides an outline of approaches for the reporting of emissions captured in one country and transported across boundaries for the purpose of storage in another (refer page Chapter 5, 5.20).

The Institute suggests that the SBSTA might also consider playing a separate role in encouraging those UNFCCC Parties who are also Party to the London Protocol to join Norway in ratifying the London Protocol Amendment to provide for the transboundary movement of carbon dioxide for the purposes of geological storage in the sub-sea bed.

The Institute considers the financial provisions contained within the M&Ps recently adopted at COP 17 for CCS in the CDM are adequate and that any need for a global reserve is unnecessary.

New Market Based Mechanisms

The Institute strongly supports the development of new and scaled-up market mechanisms to complement the Kyoto Flexibility Mechanisms and to better support the striking of commercially viable business cases to assist the global deployment of CCS. At this time, it appears that the two most popular approaches to establishing NMBMs, being discussed by Parties are: sectoral trading approaches (that complement the project based mechanisms), and various crediting arrangements for National Appropriate Mitigation Actions (NAMAs).

NMBMs should be designed in such a way so as to not preclude critically important technologies that are capable of delivering the lion's share of the required global abatement within the critical time frame and which have institutional legitimacy such as CCS.

It seems clear that regardless of whether NMBMs are project based (ie. to generate offsets) or more sectorally based (i.e. sectors with emission reduction targets), more ambitious emission reduction targets are needed in order to give a strong demand signal to carbon markets and further motivation to Non Annex I countries to go beyond UNFCCC funded mitigation actions.

More information

This article originally appeared as a blog on the Global CCS Institute website by Mark Bonner, Principal Manager of the Policy, Legal and Regulatory team at the Institute.

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Policy, company and regulation news

Global CCS Institute and China sign cooperation agreement

www.globalccsinstitute.com

The Global CCS Institute and China's Department of Climate Change, National Development and Reform Commission (DCC-NDRC) have signed a Memorandum of Understanding (MOU) regarding cooperation on CCS.

The key areas of cooperation identified under the MOU include: the promotion of technical and non-technical cooperation; encouraging further research, development and demonstration projects; developing industrial and academic networks; and promoting greater cooperation on CCS both within China, and internationally.

"The potential for deploying CCS in China is considerable given China's large fossil energy use, significant coal reserves and coal-based industries" said Brad Page, CEO of the Global CCS Institute.

"Today's MOU signing signifies a concrete step in fostering closer cooperation between the DCC-NDRC and the Global CCS Institute and provides the framework for the delivery of future key joint initiatives," he said.

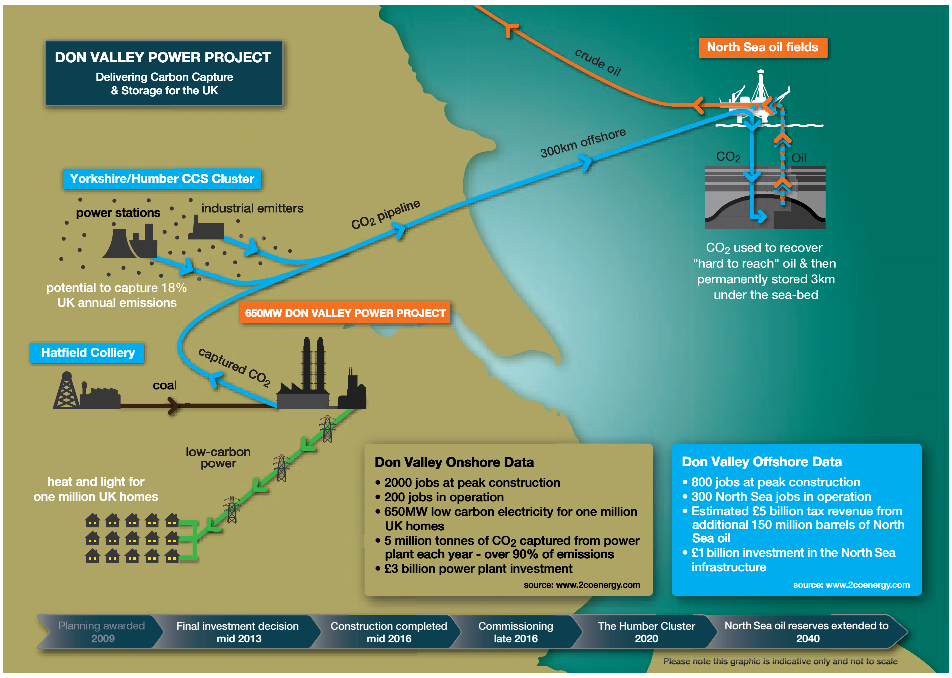
A two-day course on CO2 Storage and Enhanced Oil Recovery is being held in conjunction with the MOU Signing Ceremony, marking the first joint initiative under the MOU.

"China attaches great importance to addressing the climate challenge and CCS can be an important tool for controlling and reducing carbon emissions. China attaches great importance to the demonstration and deployment of CCS technologies," said Su Wei, Director General of DCC-NDRC.

"CCS still faces some challenges including the high cost and energy penalty and while costs are likely to come down as we improve our understanding and optimisation of the technology, the utilisation of CO2 for EOR and other industrial purposes will be important to our development pathway," Su added.

NDRC is China's lead governmental body responsible for formulating and implementing strategies of national economic and social development, including addressing climate change and developing CCS.

DCC-NDRC joined the Global CCS Institute on behalf of the Government of the People's Republic of China as a Foundation Member in 2008 and formalised their membership by signing on as a Legal Member in 2010.



Samsung buys stake in UK CCS project

www.2coenergy.com

Samsung C&T (Construction & Trading) has agreed to take a strategic 15 per cent stake in 2Co Energy's Don Valley Power Project.

The planned 650MW Don Valley Power Project in South Yorkshire will aim to capture at least 90 per cent of its CO2 emissions and provide low carbon electricity to the equivalent of a million UK homes from the end of 2016. It will use the captured CO2 to recover around 150 million barrels of North Sea oil before permanently storing it in the oil fields.

The oil produced could significantly reduce the overall cost of CCS to the UK.

The deal will see Samsung C&T take on the Engineering, Procurement and Construction (EPC) contract for the onshore power project in South Yorkshire.

Total investment in the onshore power project is expected to be about £3billion. Planning permission for the power plant has already been granted and 2Co Energy plans to start main construction in 2013 if its bid to win a further round of EU and UK funding is successful.

Summit Power to enter UK CCS delivery competition

www.summitpower.com

Summit Power Group has entered into an agreement with National Grid and Petrofac to seek funding under the UK's Carbon Capture & Storage Delivery Competition.

The funding is sought for the development of a low-carbon power plant — including full-chain, commercial-scale carbon capture and storage — in the United Kingdom. The project would be named the Caledonia Clean Energy Project.

The proposed power plant will be based at the Port of Grangemouth, west of Edinburgh on the Firth of Forth, Scotland. With more than 90 percent carbon capture, the coal feedstock plant would generate low-carbon electric power and produce hydrogen gas for commercial use. The CO2 captured will be transported via pipeline to St. Fergus by National Grid Carbon and then transferred offshore for geological sequestration deep under the North Sea by Petrofac subsidiary, CO2DeepStore.

The project site has been selected to take advantage of synergies with other facilities for industrial gas supply and to support CO2 capture. The location provides the benefit of being close to the UK North Sea for both CO2 storage and, later, enhanced oil recovery opportunities, and enables the re-use of existing pipelines.

Summit Power is currently developing a very similar project in Texas – the Texas Clean Energy Project (TCEP) – and intends to replicate many aspects of TCEP at Grangemouth. Summit Power's TCEP project is a CCS project for the U.S. Department of Energy.

UK launches £20 million CCS competition

www.decc.gov.uk

The UK Department of Energy & Climate Change (DECC) is launching a competition worth up to £20 million to fund the development of innovations in CCS technology.

Bids are being invited to develop better and cheaper CCS components and systems for pilot scale demonstration. These will support the development of CCS, which is crucial if the UK is to meet its climate change targets and reduce emissions.

The innovations could be incorporated into the UK supply chain and reduce the cost of future commercial CCS deployment in the UK, for an industry which is estimated to be worth as much as £6.5 billion a year by the late 2020s.

This £20 million competition is in addition to the £1 billion the UK has separately committed to funding commercial scale CCS projects, under DECC's CCS Commercialisation programme. A competition for that programme will be launched in the coming weeks.

The £20 million is part of a four year, £125 million Government-led CCS research and development programme. This cross-Government programme is delivered by the Department of Energy and Climate Change, the Technology Strategy Board, the Energy Technologies Institute and the Research Councils.

University of Glamorgan secures €9 million for CCS research

www.glam.ac.uk

The University of Glamorgan has secured over €9 million from the European Commission for a research project which will investigate how coal can be burnt so as to facilitate CCS.

The Reliable and Efficient Combustion of Oxygen/Coal/Recycled Flue Gas Mixtures project (RELCOM) is designed to undertake a series of applied research, development and demonstration activities involving both experimental studies and modelling work to enable full-scale early demonstration oxyfuel plant to be designed and specified.

Professor Steve Wilcox of the Faculty of Advanced Technology who is leading the project said, "Improvement of cycle efficiency and increased use of biomass help to reduce CO2 emissions in the near term, but the longer term need to move to near-zero emission power generation will require the deployment of carbon capture and storage (CCS) technologies for the fossil fuel generation of electricity."

Oxyfuel combustion is a CCS technology where fossil fuel is fired with oxygen instead of air, the flue gases then largely consist of CO2 and water vapour so that CO2 purification is more easily achieved.

A major challenge exists to lower the resulting flame temperatures which can be achieved through recycle of the flue gases. This mitigates the flame temperature making oxyfuel combustion suitable for retrofit or new-build coal power plant. Other advantages include virtually zero emissions of the oxides of nitrogen and a significantly smaller carbon capture plant.

Oxyfuel combustion has been demonstrated at approximately 40MWt but commercial-scale demonstration is the next necessary step and there are significant barriers to this happening.

Led by the University of Glamorgan, the project will be undertaken by a consortium of 19 European higher education institutions, research centres and industrial partners.

EPA proposes first carbon pollution standard for future power plants

www.epa.gov

The U.S. Environmental Protection Agency (EPA) today proposed the first Clean Air Act standard for carbon pollution from new power plants.

The rule proposed only concerns new generating units that will be built in the future, and does not apply to existing units already operating or units that will start construction over the next 12 months.

"Today we're taking a common-sense step to reduce pollution in our air, protect the planet for our children, and move us into a new era of American energy," said EPA Administrator Lisa P. Jackson. "Right now there are no limits to the amount of carbon pollution that future power plants will be able to put into our skies – and the health and economic threats of a changing climate continue to grow. We're putting in place a standard that relies on the use of clean, American made technology to tackle a challenge that we can't leave to our kids and grandkids."

Currently, there is no uniform national limit on the amount of carbon pollution new power plants can emit. As a direct result of the Supreme Court's 2007 ruling, EPA in 2009 determined that greenhouse gas pollution threatens Americans' health and welfare by leading to long lasting changes in our climate that can have a range of negative effects on human health and the environment.

The proposed standard is flexible and would help minimize carbon pollution through the deployment of the same types of modern technologies and steps that power companies are already taking to build the next generation of power plants. EPA's proposal is in line with these investments and will ensure that this progress toward a cleaner, safer and more modern power sector continues.

The proposed standards can be met by a range of power facilities burning different fossil fuels, including natural gas technologies that are already widespread, as well as coal with technologies to reduce carbon emissions. Even without today's action, the power plants that are currently projected to be built going forward would already comply with the standard. As a result, EPA does not project additional cost for industry to comply with this standard.

Prior to developing this standard, EPA engaged in an extensive and open public process to gather the latest information to aid in developing a carbon pollution standard for new power plants. The agency is seeking additional comment and information, including public hearings, and will take that input fully into account as it completes the rulemaking process. EPA's comment period will be open for 60 days following publication in the Federal Register.

Canadian government provides $14million funding for Aquistore project

www.ptrc.ca

The Government of Canada is contributing $9 million through its ecoENERGY Technology Initiative and $5 million through Sustainable Development Technology Canada (SDTC) to the Aquistore Project.

Aquistore, a CO2 storage project located near Estevan, Saskatchewan, is being managed by the Petroleum Technology Research Centre (PTRC) in collaboration with partners in the private sector and academia. The Saskatchewan Ministry of Environment is also investing $5 million through its Go Green Fund.

The project seeks to demonstrate that storing CO2 underground in a brine and sandstone water formation is a safe, workable solution. It is anticipated that captured CO2 from SaskPower's Boundary Dam Power Station will be used.

"This federal and provincial support to undertake independent research is essential for the future of carbon capture and storage advancement in Canada and the world," said Malcolm Wilson, Chief Executive Officer of PTRC. "The learnings from Aquistore will be transferable to industry and governments globally and will help inform the creation of industry-wide CO2 capture and storage regulations and policies."

Capture news

Mitsubishi to build Qatar CO2 recovery plant

www.mhi.co.jp

Mitsubishi Heavy Industries (MHI) is to build, through subsidiary MHI Industrial Engineering & Services (MIES), a large-scale CO2 recovery plant for Qatar Fuel Additives Co (QAFAC), a major fuel additive producer in Qatar.

The CO2, which is to be recovered at up to 500 tons per day will be used to increase production of methanol. This is the first overseas order for an MHI CO2 recovery plant specifically targeted at raising methanol production. Construction of the plant should be completed in October 2014.

The CO2 recovery plant, which will be built within QAFAC's methanol production plant near Doha, will capture CO2 from combustion exhaust gas emitted in the methanol production process. The CO2 separated and recovered from the flue gas using MHI's proprietary KS-1™ solvent will be provided as feedstock for boosting methanol production.

In conjunction with plant order, MHI will license its CO2 recovery technology to QAFAC through MIES. MIES will be responsible for engineering, procurement and construction (EPC), and Mitsubishi Corporation will handle the trade particulars.

Although MHI has previously licensed its CO2 recovery technology to many plants around the world, the QAFAC order represents only the third licensing-plus-EPC order for one of its CO2 recovery plants.

MHI's CO2 recovery technology is known as the KM CDR Process®. It uses the company's proprietary KS-1 solvent for CO2 absorption and desorption, which MHI and Kansai Electric Power developed jointly. To date MHI has delivered nine commercial CO2 recovery plants in Japan and other countries, and another plant is currently under construction.

In addition to urea and methanol production, CO2 recovery technology can be employed in other chemical applications such as production of dimethyl ether (DME). Other important applications possible are carbon capture and storage (CCS) and enhanced oil recovery (EOR).

SaskPower & Hitachi to build CCS test facility

www.saskpowercarboncapture.com

SaskPower and Hitachi Ltd are partnering to construct a $60 million carbon capture test facility (CCTF) at SaskPower's Shand Power Station in southeastern Saskatchewan.

The CCTF will allow international developers to fully evaluate performance of their systems to capture carbon dioxide emissions from coal-fired thermal power plants.

SaskPower and Hitachi will each contribute approximately $30 million to the CCTF, with SaskPower acting as owner/operator. Construction will begin in late 2012 or early 2013, with a scheduled completion date of summer 2014. Hitachi will supply their skilled process development team, as well as core process equipment from their Saskatoon manufacturing facility.

Hitachi's proprietary amine technology will be the first technology tested at the CCTF. SaskPower expects to evaluate a number of current and emerging carbon capture technologies over the life of the facility. The CCTF has been built to accommodate a wide range of test configurations, ensuring it remain a viable facility for many years.

In addition to the CCTF, SaskPower will be among the first electric utilities in the world to operate a commercial-scale power plant with a fully-integrated carbon capture and storage operating system. The $1.24 billion project to rebuild a coal-fired unit at the Boundary Dam Power Station and equip it with a fully-integrated carbon capture system will allow for the generation of low-emission electricity and the capture of carbon dioxide for oil extraction.

European Octavius project launched

www.ifpenergiesnouvelles.com

The inaugural meeting of the Octavius project dedicated to post-combustion CO2 capture has been held at the Solaize site of IFP Energies Nouvelles (IFPEN).

The objectives of the Octavius project are to:

- prepare for the first CCS demonstrations on a thermal power plant scale;
- implement first-generation CO2 capture processes using amine-type solvents, and
- demonstrate the DMX™ second-generation post-combustion capture process resulting from IFPEN research on an industrial scale.

Three CO2 capture pilot units – the Cato pilot unit in Maasvlakte (Netherlands), the Enel pilot unit in Brindisi (Italy) and the EnBW pilot unit in Heilbronn (Germany) – will be used to test the operability and flexibility of these first-generation processes.

The demonstration of the DMX™ second-generation post-combustion capture process will be conducted at the Brindisi thermal power plant on the Enel pilot unit, capable of capturing up to 2.25 tCO2/h on coal combustion flue gases.

Coordinated by IFPEN, Octavius brings together 17 partners from the worlds of research and industry and is scheduled to last 5 years. The project has a total budget of €13.5 million, €8 million of which will be provided by the European Commission.

CO2 Capture Project publishes Stakeholder Issues report

www.co2captureproject.com

The CO2 Capture Project has made available findings from its recent CCS Stakeholder Issues Review and Analysis Report.

The report identifies and evaluates key concerns amongst NGOs, the public and politicians at both a local and a global level, to gain greater understanding of the sensitivities surrounding CCS projects. It focuses on Australia, Brazil, Canada, the EU and the USA.

CO2 storage with geothermal energy production

HMC's proprietary carbon dioxide plume geothermal (CPG) technology has the potential to enhance the feasibility and economic viability of carbon capture and geologic storage by offsetting or eliminating the cost of CCS through generation of renewable geothermal electricity.

By Stephen O'Rourke, President, Heat Mining Company LLC (HMC); Kenneth Carpenter, Managing Partner, HMC; Dr. Jimmy B. Randolph, HMC; and Dr. Martin O. Saar, University of Minnesota (UMN)

The release of the greenhouse gas carbon dioxide (CO2) into the atmosphere from human activity is considered by many experts as the main driver of current global warming (IPCC, 2007). One option for reducing this release is to capture CO2 at stationary locations where it is emitted, such as fossil-fuel-burning power plants, then inject and permanently store it as supercritical CO2 in partially depleted hydrocarbon formations (enhanced oil recovery, EOR) and deep saline (and thus largely unusable) aquifers.

However, the cost of such carbon capture and storage (CCS) is high (IEA, 2010) and large-scale implementation is not economically feasible unless stored carbon has a monetary value (for example in a carbon cap and trade market) or can be used to generate revenue.

Heat Mining Company LLC's (HMC) patent-pending process of using CO2 as the subsurface working fluid in geothermal power generation at typical CCS or EOR sites (i.e., naturally permeable and porous formations in sedimentary basins) could be the first step toward an economical carbon-neutral or even carbon-negative power industry. This process would help reduce point-source CO2 emissions and potentially produce enough power to offset the cost of CCS or even make it a profitable activity.

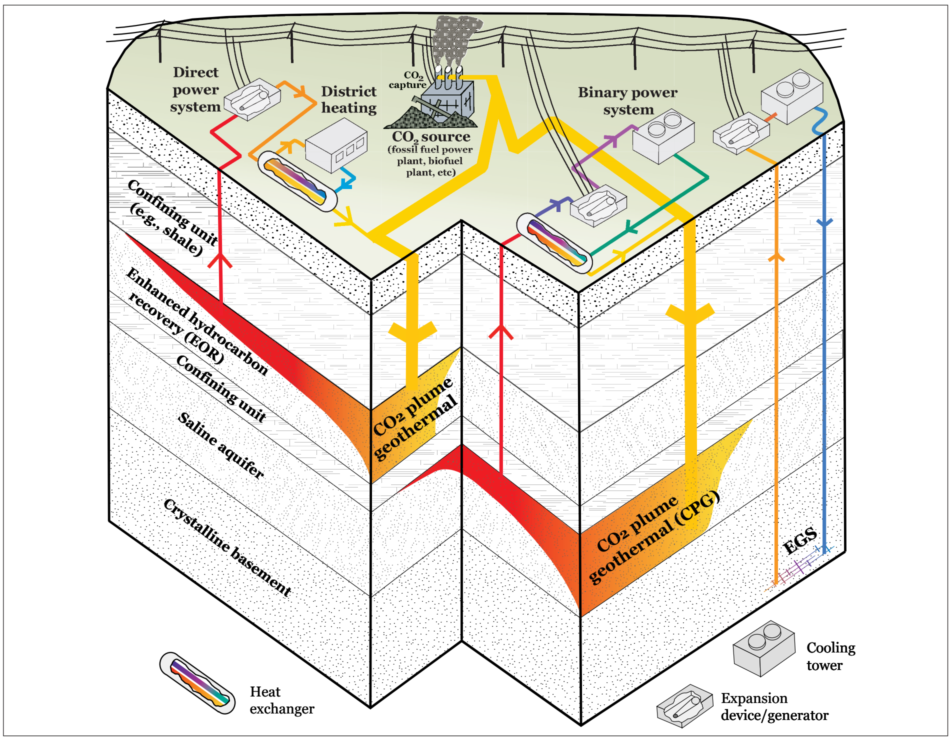


Figure 1 - Potential implementations of CO2 based geothermal systems, including CPG in saline aquifers or as a component of EOR projects (modified after Randolph and Saar, 2011)

HMC's CPG technology

HMC's CPG technology was developed at the University of Minnesota by Dr.'s Martin O. Saar, Jimmy B. Randolph, and Thomas Kuehn with the support of the Institute for Renewable Energy and the Environment (IREE). It uses CO2 captured from an emitter or injected into hydrocarbon reservoirs from EOR activities to generate clean, renewable electricity while geologically sequestering the CO2.

The CO2 is compressed and injected into a deep reservoir. After being geothermally heated, the CO2 rises buoyantly and pools below a caprock. The heated CO2 is produced to the surface through a well, is separated from any water or hydrocarbons that may be present, expands to turn a turbine, and is then condensed in a heat exchanger before being reinjected into the subsurface, closing the loop so that no CO2 is released to the atmosphere (Fig. 1).

Alternatively, in an indirect system (useful if significant free-phase water is present), the heated CO2 is passed through a heat exchanger that provides thermal energy to, for example, an organic Rankine cycle power system. Once the power loop is filled with CO2, 100% of the CO2 mass coming from the emitter is permanently sequestered underground. Several variations, including cogeneration of both electricity and heat, can be envisioned.

In all CPG operations, CO2 is injected into geologic formations under supercritical conditions (liquid-like density, gas-like viscosity) at depths of 0.8 to 5 km. At such depths, water in aquifers is typically highly saline and thus generally considered non-potable. Formations of interest for CPG are isolated from surface and potable-water aquifers by one or more overlaying layers of low-permeability caprocks. In fact, many constrained sedimentary formations have trapped hydrocarbons and/or naturally occurring CO2 for millions of years.

Efficiency of CPG systems

CPG systems are expected to operate at 1.5 to 4 times the electricity-production efficiency of conventional water-based geothermal systems, reservoir temperature, pressure and permeability being equal. For example, a CPG system using a 100 °C, 2.5 km deep reservoir (low to moderate geothermal gradient) with permeability of 50 mD (moderately permeable sedimentary formation) operates at 11.8 percent efficiency of energy conversion from geothermal heat to electricity.

In comparison, the same formation operating a binary power system on native formation water/brine yields 3.4 percent energy conversion efficiency. All calculations include losses due to friction, pumping if necessary, and losses in the power system; however, note that site-specific geologic conditions will affect efficiency.

An operating CPG system will extract less heat energy from a formation than a comparable water-based system while producing more electricity or heat for space/water use, extending the longevity of a given geologic unit. CPG efficiency is particularly high in moderate temperature (70–150 °C) and tight (5–500 mDarcy) formations, where water-based geothermal is rarely viable because of low power conversion efficiencies and high parasitic pumping power requirements.

In contrast, as a result of CO2's thermodynamic properties (low viscosity at relatively high densities and simultaneous high expansivity), CPG does not require pumping except at extremely low formation permeabilities of less than 0.5 mD (Randolph and Saar, 2011). Hence, overall system efficiencies for CPG at low temperatures are as high as traditional water-based systems at much greater temperatures.

HMC is developing applications of CPG technology for three areas of energy production:

- large-scale commercial electrical production at CCS sites
- moderate-scale electrical production at EOR sites to power operations
- small to moderate storage of electrical power at wind farms

Large-scale commercial electrical production at CCS sites

CO2 – In the best-case scenario, CO2 is in the ground or sequestration is planned. Otherwise, proximity to a CO2 source is desired.
Geology – CPG allows a wider range of geologic conditions for viable power production than conventional geothermal. Temperatures above 70 °C can be used for commercial electrical power generation. Reservoir depth should be 0.8 to 5 km in a constrained aquifer below the lowest fresh water aquifer. With permeability above 5 mD, no production pumping is required.

Moderate scale electrical production at EOR sites to power operations

CO2 – Ideally, CO2 has largely displaced all or most oil at a site, permitting use of a CO2 turbine. Otherwise a binary power system must be used, possibly in conjunction with surface separation, which can handle a produced fluid stream of water + hydrocarbons + CO2.
Geology – Temperature and pressure are established by the depth and size of the EOR reservoirs. A 50 °C difference between produced fluid and surface temperatures is generally required to generate greater than 1 MW of power. Total power generation depends on the volume of CO2 emplaced at depth and the ratio of CO2 to oil + water in the produced flow. The high mobility of CO2 generally ensures that the system will achieve better flow than any oil in the field.

Small-to-moderate storage of electrical power at wind farms

CO2 – A relatively small amount of CO2 may be required. Preferably, CO2 is already in the ground or a CO2 source is located nearby. Alternatively, CO2 could be stored in a surface tank.
Geology – Low required aquifer temperatures and poor permeability permit application over a wide range of geological conditions. A produced fluid temperature that is 10 °C above atmospheric conditions may allow 100 percent or greater return of stored energy. Produced fluid temperatures more than 25 °C above surface temperatures result in significantly greater electricity production than the amount stored. Shallow depths (0.5 to 2km, below lowest potable aquifer) and low permeabilities (0.5 mD and above) are viable.

Benefits of using CO2 rather than native reservoir water/brine as the subsurface geothermal heat exchange fluid

CO2 mobility (fluid density divided by dynamic viscosity) at the subsurface temperature and pressure conditions of interest is substantially greater than the mobility of pure water (up to 5 times) and brine (up to 10 times). Mobility is the tendency of a fluid to preserve momentum; supercritical CO2, with its liquid-like density but gas-like viscosity, moves much more effectively through a geologic formation than does water. Therefore, CO2 efficiently "mines" geologic heat and requires little pumping to establish fluid flow. High CO2 mobility more than compensates for the lower heat capacity of CO2 compared to water.

High CO2 expansivity with increases in temperature, together with high fluid mobility, generally eliminates the need for fluid pumping (a significant parasitic power draw in water-based geothermal systems) within the CPG power cycle. High CO2 compressibility produces large (70 bar or greater) pressure differences between injection and production wellheads, providing substantial potential for power generation.

This pressure differential allows CO2 geothermal systems to use direct power conversion equipment even at low formation temperatures, as opposed to the binary equipment with a heat exchanger required for comparable water-based systems. The heat exchangers in conventional binary water-based geothermal systems constitute much of their capital and operational cost and operational efficiency loss.

Thus, direct CO2 geothermal systems may cost less than half of what conventional water-based binary systems cost (U.S. Department of Energy Geothermal Peer Review Meeting, June 2011).

CPG systems avoid use of clean water, an increasingly limited resource, for geothermal development. Moreover, they sequester anthropogenic CO2, offsetting the cost of CO2 storage through energy sales and providing electricity for CO2 storage. Concurrently, CPG would provide the potential for generating revenue from elimination of atmospheric CO2 emissions, depending on local policies.

Moreover, CO2 that contains no free-phase water has very low mineral solubility and reactivity, unlike pure water. In CO2 geothermal operations in which production wells tap into an established CO2 plume, produced fluids are largely nonreactive, minimizing scaling and degradation of power equipment. It will not always be possible to ensure that there is no produced water, and CO2 with free phase water will result in a mild acid. However, acidic production fluid is well understood in conventional geothermal developments and can be dealt with.

Approach for controlling the subsurface

CPG sites will be chosen and developed to maximize predictability of CO2 plume evolution. For example, preferable early-stage reservoirs will contain either domes or inclined structures. Plume evolution and shape can also be controlled by dynamic reservoir management – strategically pumping and reinjecting native formation fluid from a reservoir at some distance from the plume to control the reservoir pressure field and associated plume movement. Dynamic reservoir management is an area of active research in the U.S. (e.g., at Lawrence Livermore National Lab).

CPG potential

Earth's continental crust temperature increases ~30–35 °C per kilometer depth on average (Pollack et al., 1993), and significantly more in geothermally active regions. This geothermal resource could be tapped to provide as much as 200,000 EJ of electrical

energy in the United States – 2,000 times the total 2005 U.S. energy consumption (Tester et al., 2006). CPG is particularly capable of harvesting geothermal energy from areas not viable for conventional technologies.

With reasonable assumptions, CPG has the potential to produce 150 GW of power, and possibly much more, in the U.S. To determine this estimate, we overlaid U.S. temperature at 2.5 km depth with sedimentary basins suitable for CPG development. We then assumed CPG installation over 4 percent of this suitable space and 2.5 MW (a very small system) per installation.

Note that this estimate is conservative; it does not include the possibility for vertically layering CPG installations within a single formation, vertically layering separate aquifers at a given map-view location, or using sedimentary formations shallower or deeper than 2.5 km (e.g., the Kennedy Basin in South Dakota) or larger power systems (which could be installed at all sites, particularly those with temperatures >100 °C). Furthermore, only the contiguous U.S. is included in this estimate, while significant geothermal resources exist in Alaska and Hawaii as well as in many regions worldwide, particularly Canada, Australia, Europe, China, and Indonesia.

Summary – Why CPG?

- Negative atmospheric CO2 emissions
- High power system efficiency
- High fluid mobility = efficient geothermal heat mining
- Thermosyphon = minimal or no parasitic power losses
- Patented CPG turbine and modeling technologies

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More information

Anyone interested in producing or storing power from a saline aquifer using CO2 as the working fluid is welcome to contact HMC for information on planning and completing a CPG project:

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CO2 Capture Project CO2 impurities study

The CO2 Capture Project (CCP) has completed the first phase of a study into the impact of CO2 impurities on geological storage of CO2. The potential for cost savings by delivering less pure CO2 streams to the storage reservoir are significant if it can be shown that these impurities do not adversely impact injectivity, conformance or containment.

Through reservoir simulation and laboratory experiments, the CCP is building an understanding of the potential impacts to storage containment as a result of impure CO2 streams.

The study is being undertaken in conjunction with the Bureau for Economic Geology at the University of Texas at Austin.

The CO2 streams captured from industrial emissions sources as part of Carbon Capture and Storage (CCS) projects are expected to contain various impurities depending on the process and extent of post-capture gas treatment. The potential for cost savings by delivering less pure CO2 streams to the storage reservoir are substantial if, transportation notwithstanding, it can be shown that these impurities do not adversely impact injectivity, conformance or containment.

Non-compressible gases (e.g. N2, CH4, Ar) would be expected to impact flow properties and dynamics of the CO2 stream whereas reactive gases (e.g. CO, SOx) may

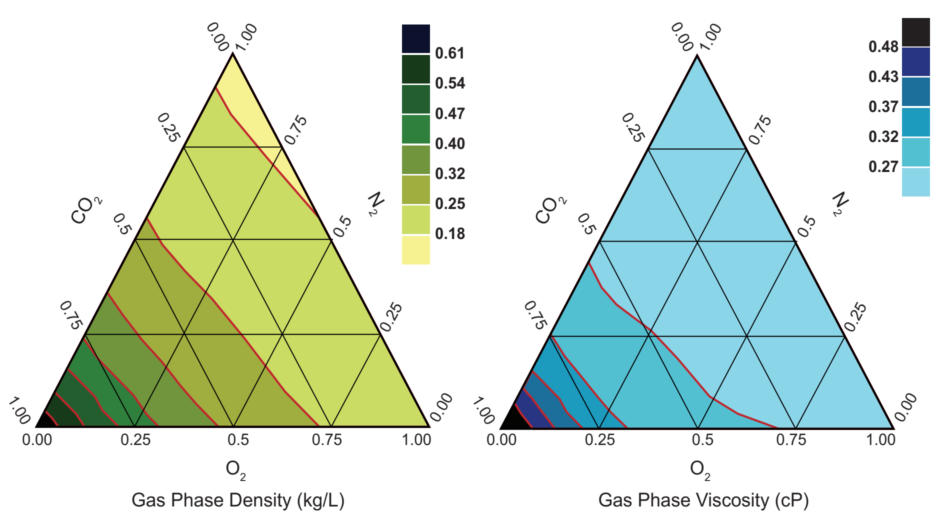


FIG1: CO_2 impurities impact on mixed gas plume density and viscosity

In all cases, viscosity and density of the mixtures are lower than that of pure CO_2 (only SO_2 would have the opposite impact). Figure 1 displays mixture density (left) and viscosity (right) properties expected at ~1.5 km (~5000 ft) deep U.S. Gulf Coast reservoir at 58ºC (135ºF) and 17 MPa (2500 psi)

result in dissolution or precipitation of minerals which could impact reservoir or seal permeability and mechanical strength. The behavior of other gases (e.g. H2, O2) is likely to be complex in terms of plume dynamics and reactivity. Through reservoir simulation and laboratory experiments, the CO2 Impurities Study aims to understand potential impacts and complications to storage containment as a result of variously impure CO2 streams.

The project is divided into three phases:

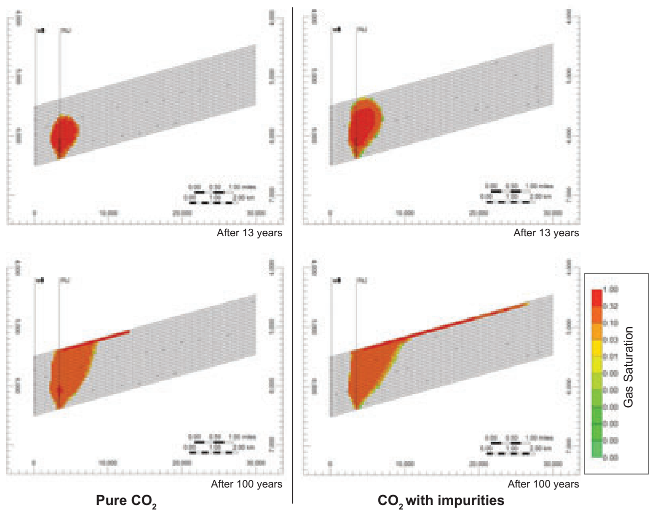
1) Reservoir Simulation - Develop static reservoir models encompassing a range of heterogeneity. Simulate injection and plume migration of CO2 streams with single and multiple non-compressible gas impurities with the following maximum concentrations (mol%): N2 (15), O2 (5), Ar (5) with CH4 considered as an impurity 'ex-solved' from brine. Plume behavior metrics (rate of vertical ascent, lateral extent and time for CO2 trapping) were examined for low dip reservoir models at two depths: 1.5 and 3 km (~5000 and 10,000ft, called 'shallow' and 'deep' respectively) and at temperatures of 60°C and 125°C and total dissolved solids concentrations of 100,000 and 180,000 mg/liter, respectively.

2) Static Experiments - Conduct batch autoclave experiments using pure CO2 and CO2:O2 (95:5mol%) with reaction modeling of other species SOx (0.15mol%), CO (2mol%), and H2 (0.4mol%). Detailed pre- and post-reaction water chemistry and rock petrographic, petrophysical and chemical analyses will be used to document alteration for the CO2 and O2 and to 'history match' the experiments using batch geochemical numerical code.

3) Integration – Flow and geochemical results will be integrated into a framework to assess the impact of impurities on plume shape and evolution, CO2 storage capacity, storage reservoir integrity and well injectivity.

FIG 2: CO_2-stream impurities impact on lateral extent of CO_2 plume (shallow depth - axes in feet)

Pure CO_2 is injected in the lower part of a sloping aquifer for 30 years at a rate of 0.74 million m^3/day (26 MMSCFD) (top left). The CO_2 plume migrates upward, assuming homogeneous permeability in the field, until it reaches the top of the formation. Once the top is reached, the plume progresses up dip until the injected material is exhausted and entirely trapped through residual saturation and dissolution (chart bottom left). For the 81mol% CO_2 (N_2,15%; O_2, 2.1%; Ar, 1.7%) impurity case (top right) migration is faster because mixtures or non compressible gases always have a lower density (and thus greater buoyancy) and viscosity than pure CO_2. After 13 years of injection, the mixed-gas CO_2 has already reach the top of the formation whereas pure CO_2 has not (top right and left, respectively). At 100 years after start of injection, mixed-gas CO_2 (bottom right) has advanced further than pure CO_2 (bottom left) and ultimately mixed-gas CO_2 is trapped faster with no remaining mobile gas than pure CO_2.



Phase One results - reservoir simulation

Flow Dynamics

Because of the lack of accurate data on viscosity and density, a series of experiments was performed at selected pressures and temperatures and for selected multi-component gas mixtures to accurately determine their physical characteristics (PVT data) (Figure 1).

In addition, a comprehensive literature audit helped in estimating aqueous solubility of the mixture components at various pressure, temperature, and salinity conditions.

Impurities impact static capacity through variations in density and viscosity of the CO2-rich mixture. A lower density impacts CO2 capacity not only because of the smaller fraction injected and space needed for storing impurities but also because of the generally lower density of the impurities at the same conditions. An approximate proxy for capacity change owing to impurities is given by the density ratio. The loss in capacity can be as high as >50% at very shallow depths (~3000 ft, CO2 and 15% molar N2) but the difference quickly decreases with depth. Similarly, mass injectivity, measuring how CO2 can be injected (represented by the proxy metric of density over viscosity ratio), also shows a decreased value at shallow depths that recovers with increasing depth.

Dynamic reservoir simulations revealed that impurities impact CO2 plume shape (rate of vertical ascent and lateral extent) more markedly at shallow depths where the contrast in density and viscosity with pure CO2 is at its largest (Figure 2). For example, a 4% mole fraction impurity in a binary system is sufficient to increase plume length in 'shallow' low-dip sloping layers by 25%, whereas a mole fraction of 9 to 15%, depending on the component, is needed to create the same impact in a 'deep' system. It also revealed that because O2, N2, and Ar have similar physical properties, their impact on CO2-dominated mixtures is comparable, particularly at low concentrations (e.g., 2 mol%), thus they can be merged in one unique component with properties of N2 during the numerical modelling.

In all cases, plume extent is greater when impurities are present although residual trapping (retention in pores by capillary forces) occurs more rapidly. This is generally the case regardless of reservoir heterogeneity and complexity although heterogeneity tends to moderate the impact of impurities on plume extent. The modeling also shows differential dissolution at the front and edges of the plume. In general, there is a trade-off between larger plume lateral extent due to the presence of impurities and decreased risk owing to faster trapping (pressure management).

Implications for cost-effectiveness and security of CCS

From these findings, the implications for the cost of capture and the reliability of long term geological storage could be significant. Long term reliability of CO2 storage seems unlikely to be compromised by the presence of impurities in the CO2 stream – indeed trapping timescales may be reduced in many cases, thereby decreasing risk to containment.

However, given that the presence of impurities is likely to impact the behavior of the CO2-dominated plume, more attention to reservoir modelling prior to injection, plume management and surveillance during operations should be factored into commercial project planning.

The later phases - static experiments and integration - are expected to be completed later this year.

More information

The CO2 Capture Project (CCP) is a partnership of several major energy companies working together to advance the technologies that will underpin the deployment of industrial-scale CO2 capture and storage.

www.co2captureproject.com

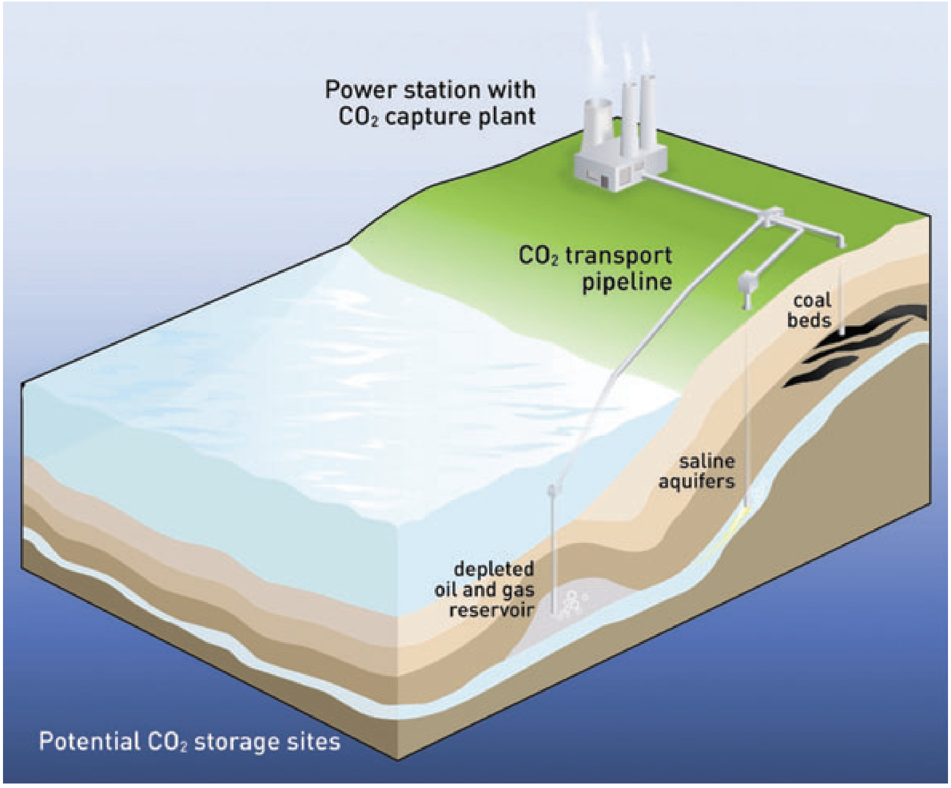
CCS measurement challenges

One of the remaining challenges to be overcome in establishing CCS as a practical operational process is effective measurement and monitoring of the CO2 stream.

John Morgan, Carbon Capture & Storage Business Manager, and Philip Cherukara, Consultant for Sustainable Energy, NEL

Energy demand is predicted to double over the next two decades, with fossil fuels set to supply more than half of the world's energy needs through to 2030. This means that Carbon Capture and Storage (CCS) will play a prominent role in the abatement of anthropogenic CO2 emissions as part of a secure and sustainable global energy supply.

One of the many technical challenges to be overcome in establishing CCS as a practical operational process is effective measurement and monitoring. This will be a key element of the CCS regulatory framework (as reflected in the EU CCS Directive) which calls for CO2 flow measurement, composition measurement, leak detection and quantification across the full CCS chain. Accurate measurement will be essential to environmental and safety needs and fundamental in reducing financial exposure in CO2 trading schemes. To this end, the European Union Emissions Trading Scheme (EU ETS) Monitoring and Reporting Guidelines set stringent measurement and monitoring criteria.



Transportation of the CO2 to its final storage destination is claimed to be more economical by pipeline, especially if cluster networks are formed for multiple emitters. Typically dedicated CO2 pipelines are designed to transport CO2 well above critical pressure, so that it will be in dense phase, which means pipelines will be operating away from the phase boundary. However, in many instances, existing pipelines will be utilised for transportation which do not permit operations at pressures well above critical pressures.

Compared to other substances that are transported by pipeline (e.g. oil, natural gas and water), CO2 is unusual because its critical temperature lies close to ambient temperature, which is the normal operating condition and the region where most industrial processes are carried out. This means that even small changes in pressure and temperature may lead to rapid and substantial changes in the physical properties of CO2 , such as phase, density and compressibility.

Therefore, not only is there a risk of changing between phases, but also when operating on or close to a phase boundary, multiphase flow conditions can arise. This means that phase changes and multiphase flow occurring at measurement points will have a detrimental effect on measurement accuracy, especially when most measurement devices are designed to operate only in single phase.

Measurement would be more accurate if CO2 was being transported in only gaseous phase or single phase (at all times and throughout the transportation system). However, CO2 is usually only transported in the gaseous phase when low volumes of CO2 have to be transported or if the pipeline is being reused. In addition, if the transported fluid contains 100 per cent CO2 i.e. no impurities, higher accuracy could be achieved. This is because impurities could enter the system easily because pipeline systems will have inputs from multiple capture plants with varying compositions of CO2 streams.

However, this ideal scenario simply doesn't exist, meaning measurement challenges must be addressed urgently, including flow measurement, composition measurement, physical properties measurement and leakage detection & quantification.

Flow measurement

Flow metering will be necessary for regulatory measurement under the EU ETS. This includes custody transfer/fiscal metering (where there is a transfer of ownership in the pipeline); leakage detection; and metering the various processes across the CCS network, including controlling the volume of CO2 being injected into the geological storage formation. Under the EU ETS, the mass of annually transferred CO2 is required to be determined within a maximum uncertainty of less than 1.5 per cent. For custody transfer purposes the accuracy requirements may be even higher.

To put the importance of accurate flow measurement into perspective, consider the UK's largest power station, which emits approximately 22 million tonnes of CO2 per annum. Each percentage of uncertainty in flow measurement could result in a £1.15million exposure in the trading scheme,

based on a carbon trading price of £5.20 / tonne as on 30th March 2012.

It is also clearly understood that there is an urgent need to address the issues surrounding flow measurement in CO2 transportation. One of the primary outcomes of such a programme would be the fiscal metering of CO2 with a maximum measurement uncertainty of +/- 1.5 per cent. Of course, in order to meet these targets, the behaviour of CO2 in transportation systems has to be understood. The specifications of the fluid and accurate accounting of the CO2 through all sections of CCS schemes must also be achieved.

The table opposite summarises the technologies that are currently available for CO2 flow measurement. It also describes the advantages and disadvantages of each type of technology.

Flow meter	Measurement Uncertainty	Rangeability	Pipeline diameters	Intrusive (pressure drop)	Sensitive to corrosion	Experience with CO_2	Comments/Limitations
Differential pressure (dp) meters							
Orifice Plate	< 1%	3:1	(> 1.5 inch)	high	high	yes	Rely on density, could struggle in unstable supercritical region
Venturi	1%	3:1	(> 2 inch)	minimal	high	no	Rely on density, could struggle in unstable supercritical region
V-cone	1%	> 3:1	(0.5 to 72 inch)	minimal	high	no	Rely on density, could struggle in unstable supercritical region
Volumetric flow meters							
Ultrasonic (Time-of-flight)	< 1%	20:1	(> 0.5 inch)	none	no	under development	Rely on density, potential issues with acoustic attenuation in CO_2 rich mixtures.
Turbine meters	< 1%	10:1	Gas: 0.25 – 24 inches Liquid: 0.25 – 24 inches	average	Med - high	yes	Rely on density, require to be calibrated in viscosity and conditions of use, sensitive to pulsations, behaviour unknown in supercritical fluids, limited in upper pipeline diameter size.
Vortex Meter	1%	10:1	< 16 inch	average	Medium - high	no	Rely on density, limited pipeline diameter
Mass flow meters							
Coriolis meter	< 1%	20:1	0.25 – 6 inches	average	Minimal - average	yes	Provides direct mass flow measurement, limited in pipeline diameter

Table 1 - summary of potential CO2 flow meters

Composition of the CO2 stream

Composition measurement is necessary to determine the concentration of CO2 and to detect contaminants present in the CO2 stream. This information is essential in order to understand the physical properties, chemistry and behaviour of the CO2 mixture Chemical analysis of injected fluid and gas analysis, using gas chromatographs and spectrometers, can be used for composition analysis.

The composition of the CO2 stream will, amongst other things, affect the density, compressibility and phase envelope of the gas or liquid. Therefore, in order to establish the necessary pressures and temperatures required to maintain a stable phase and economical transfer, knowledge of the composition is vital. Without this knowledge it would be extremely difficult to plan the CCS processes and undertake the necessary flow conditions to maintain a stable phase, ensure safe and economical transportation through pipelines.

Physical properties and CO2 behaviour

The presence of contaminants in the CO2 stream will significantly alter the physical properties from those of pure CO2 and it is the physical properties of the CO2 stream that dictate its behaviour under different processes and conditions. This is because the overall effect of impurities in the CO2 stream is to shift the phase boundary and create two-phase regions with the associated impact on flow measurement as described above.

Although 'equations of state' models exist for calculating the physical properties of pure CO2, the best currently available models that include the contaminants likely in CCS streams have uncertainties of at least 10 per cent in density. However, without accurate knowledge of density, it will not be possible to convert volumetric flow to mass flow.

Clearly, such models are unacceptable for converting from volumetric to mass flow when trying to meet the ±1.5 per cent uncertainty target. Further work, including modelling and experimental research, is therefore required to obtain the necessary chemistry and physical properties data to allow the planning and design of CCS schemes. In particular, the development and validation of robust equations of state from CO2 mixtures is essential.

CO2 leak detection and quantification

It is also vital that appropriate measurements are in place to detect and quantify leakage if it should occur across the CCS network. This includes from above-surface pipelines, buried pipelines, sub-sea pipelines and from the geological storage formations. However, the greatest issue in terms of leak detection is that although there are many technologies in place for detecting leakage from the storage formation, the real challenge is to quantify any and all leakage, and this is an area which requires urgent attention.

For pipelines, it is likely that a combination of methods will be used to detect CO2 leakage. These will include internal measurements such as flow, pressure and temperature, along with external methods, such a screening and sampling of the surrounding environments. In serious cases, the leakage of CO2 may be clearly visible, either by the formation of CO2 clouds in the atmosphere, or the presence of solid CO2 deposits on the ground.

Measurement, Monitoring & Verification (MMV) is a key requisite for the optimal operation and management of a CO2 sequestration site, but it presents challenges that are site-specific and ever changing. Individual CCS projects will therefore need site-specific MMV processes to ensure the captured CO2 will be injected safely and permanently for sequestration. However, it is almost impossible to recommend a set of MMV tools that could be applied universally to all CO2 storage sites because every geological storage site presents unique structures, conditions and challenges.

Measured Parameter	Probable Monitoring & Measurement Options
Spatial Distribution of CO_2 Plume	Time-Lapse Seismic, Satellite Radar Interferometer (InSAR), Micro-Seismic, Microgravity, Vertical Seismic Profiling, Cross-Well Seismic, Formation Fluid Chemistry From Monitoring Zone.
Reservoir Pressure and Temperature	Down-Hole Pressure Sensor, Bragg Fibre Optic Grating, Thermocouples.
Well Integrity	Cement Casing And Imaging Logs, Vertical Seismic Profiling, Wellhead Detection Devices, Mechanical Integrity Testing.
Amount of Any Measurable Leakage	Groundwater Sampling, CO_2 Monitoring, Artificial Tracers/Isotopes, Soil-Gas Surveys, LIDAR Atmospheric Eddy Co-Variance.

Table 2- Monitoring & Measuring Approaches [1]

The table above lists the technologies and techniques available for MMV for CO2 storage.

The issue of the long time frames that are required for MMV of CO2 sequestered in a geological formation is proving to be a great challenge to overcome. This is because monitoring plans have to be applied throughout the lifetime of a project to ensure its success. Also, the question that begs an answer is when, if ever, is it acceptable to bring MMV processes to an end at a CO2 storage facility? The greatest issue in terms of leak detection is that although there are many technologies in place for detecting leakage from the storage formation, there are currently no methods to accurately quantify leakage.

The future of accurate CCS Measurement

In CCS schemes, sampling, physical properties, flow measurement and leakage detection and quantification data are interdependent on one another. Sampling the composition of the CO2 stream will provide the necessary data to calculate the physical properties, which will then be used for flow measurement and control calculations. In particular, it will allow determination of the necessary pumping pressures and conditioning required to maintain a stable, safe and economical flow across the network. This includes using validated algorithms, models and equations of state, which will underpin online physical properties calculation software and computers.

In order to ensure effective control and fluid management of the overall system, and a smooth transition from the point of capture through to transportation and injection into the storage formation, it will be necessary to have sophisticated, on-line, interfaced measurement systems to allow constant monitoring and tracking of changes throughout the network. The use of standardised methods, industry standards, best practice guidelines, and traceable validated measurement equipment, will help minimise inconsistencies between measurement points and duty holders.

However, the current situation shows that there is little validated data available to support the performance and accuracy of various flow measurement technologies for use in CCS schemes. This reflects the lack of test and calibration facilities available worldwide to support the necessary research, development and verification of CCS flow measurement technologies. In particular there are no validated primary reference standards for flow measurement in CO2.

The UK Government's National Measurement System has recognised this requirement and has invested in innovative R&D facilities which are being developed at NEL in East Kilbride, near Glasgow to address the key metrology issues with CCS scheme development. This work includes the development of an infrastructure to incorporate CO2 flow measurement standards with three separate CO2 test facilities. These facilities will provide a platform for research and development work on measurement devices and components over a wide range of conditions that are relevant to CCS Schemes, and to develop and test recommended practices for the full- scale deployment, supporting national and international standardisation.

It is evident that there are a number of potential issues associated with the measurement of CO2 which require to be addressed to support CCS schemes. Particularly there is inadequate knowledge of the physical properties and phase envelopes relating to CO2 mixtures in CCS schemes, yet such data will be essential for controlling CCS processes and for planning and designing suitable and accurate measurement systems.

For the full- scale industrial deployment of CCS schemes it is essential that accurate and robust monitoring programmes are in place, which means much work has to be done now to address the various measurement, monitoring and verification issues across the full CCS chain.

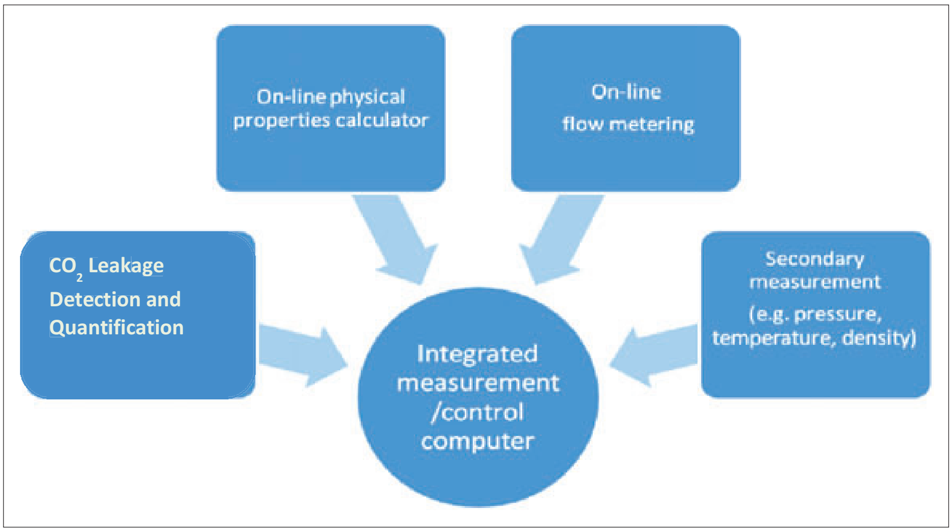


Figure 1 - integrated measurement and control system

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More information

NEL is a world class provider of technical consulting, research, measurement, testing and programme management services to clients across many industries including oil & gas, renewable and sustainable energy, process and government.

NEL also holds the UK National Standards for flow measurement and has an international reputation in key engineering areas such as flow measurement, computational fluid dynamics, environmental and thermal engineering.

www.tuvnel.com

CIUDEN's PISCO2 project commences

www.ciuden.es

The research team working at the Fundación Ciudad de la Energía (CIUDEN) has extracted 50 cubic metres of upper layer soil from the site of the future CO2 storage pilot plant in Hontomín (Merindad del Río Ubierna, Burgos, Spain).

The soil was taken to CIUDEN's facilities in Cubillos del Sil (León), where it will become part of the PISCO2 Project aimed at developing sustainable biomonitoring tools for safety control of CO2 geological storage.

The PISCO2 project starts its operational phase with 12 cells (16m² each) filled with soil from both the capture and storage sites. The cells are equipped with systems for controlled CO2 injection at different depths and devices for sampling groundwater and gases (CO2, CH4, O2). Continuous monitoring systems measure water content, pH levels and CO2 fluxes, as well as assessing potential microbiological, botanical and geochemical alterations.

The research objectives of PISCO2 include the development of biomonitoring tools for CO2 leakage in large areas, testing and development of equipment and methodologies and to serve as a laboratory for agricultural tests of the effects of low CO2 emissions.

In the future, PISCO2 expects to be available to test soil samples from all over the world. With this facility CIUDEN aims to achieve carbon dioxide control and monitoring using natural analogue methods.

CIUDEN's technicians collected soil samples from the Hontomin storage site to develop biomonitoring tools for CO2 in large areas

ETI project to develop marine subsurface monitoring

www.eti.co.uk

The UK Energy Technologies Institute is seeking partners for a project to deliver a system to provide assurance that carbon dioxide is securely stored deep underground beneath the sea bed.

The ETI has already completed two research projects on CO2 storage, one on Measuring, Monitoring and Verification (MMV) requirements for the UK and the other making an assessment of the UK's storage potential (UKSAP, the UK Storage Appraisal Project).

Together with knowledge gained from the design studies completed as part of DECC's CCS competition, the ETI has used these studies to identify capability gaps in the UK which need to be addressed in MMV.

From this analysis, the ETI has identified that the key requirement gap is for proven systems capable of detecting and measuring any leak in the shallow subsurface and the marine environment. Although leakage is expected to be very unlikely in practice, such systems will be important to provide assurance to regulators, storage providers and other stakeholders for the storage sector of the CCS industry.

The deadline for notification of intention to submit a proposal is 15 June and the closing date is 29 June.

U.S. plan to boost CO2-EOR

neori.org

The National Enhanced Oil Recovery Initiative (NEORI) has called for federal and state incentives to stimulate the expansion of enhanced oil recovery using CO2 from power plants and industrial facilities.

NEORI, a coalition of industry, state, environmental and labour leaders, suggests that the proposed measures would boost domestic U.S. oil production while reducing the nation's CO2 emissions.

In CO2-enhanced oil recovery (CO2-EOR), oil producers inject CO2 into wells to draw more oil to the surface. The practice helps sustain production in otherwise declining oil fields but limited supplies of CO2 constrain the expansion of EOR.

NEORI recommends a proposed federal tax incentive focused on companies that capture and transport CO2, not oil companies. It is estimated that the tax credit would quadruple U.S. oil production from EOR, to 400 million barrels a year, while reducing CO2 emissions by 4 billion tons over the next 40 years.

The U.S. Treasury Department would administer the competitively awarded tax credit.

NEORI calculates that the program would pay for itself within 10 years through increased federal revenues generated by boosting domestic oil production, with an estimated net return of $100 billion over 40 years. The incentive would reduce the trade deficit by saving the United States about $610 billion in expenditures on imported oil over the same period.

As an immediate measure, NEORI recommends that Congress or the Treasury Department modify the existing Section 45Q Tax Credit for Carbon Dioxide Sequestration to provide a more workable incentive to firms to capture and transport CO2.

At the state level, NEORI identified a range of existing state policies encouraging commercial deployment of CO2 capture technologies and projects and recommends that other states tailor and adopt them. The model state policies include tax credits, exemptions or abatements, and the inclusion of carbon capture-and-storage in electricity portfolio standards, among others.

In total, an estimated 26 billion to 61 billion barrels of economically recoverable oil could be produced in the United States using currently available CO2-EOR technologies and practices, or potentially more than twice the country's proved reserves. Expanded use of CO2-EOR also can advance the development of infrastructure needed for long-term capture, transportation and storage of carbon emissions.

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/publications/data/dataset/status-ccs-project-database

Asset Lifecycle Stage	Project Name	Description	Country	State / District
Operate	**Century Plant**	Occidental Petroleum, in partnership with Sandridge Energy, is operating a gas processing plant in West Texas that at present can capture 5 Mtpa of carbon dioxide for use in enhanced oil recovery. Capture capacity will be increased to 8.5 Mtpa in 2012.	UNITED STATES	Texas
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	Oklahoma
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	Saskatchewan
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	Wilaya de Ouargla
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	Wyoming
Operate	**Sleipner CO2 Injection**	Sleipner is the second largest gas development in the North Sea. Carbon dioxide is separated from produced gas at Sleipner T and reinjected into a deep saline formation above the hydrocarbon reservoir zone. This project has been in operation since 1996.	NORWAY	North Sea
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	Barents Sea
Operate	**Val Verde Natural Gas Plants**	This operating enhanced oil recovery project uses carbon dioxide sourced from the Mitchell, Gray Ranch, Puckett, Pikes Peak and Terrell gas processing plants and transported via the Val Verde and CRC pipelines.	UNITED STATES	Texas
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	Illinois
Execute	**Agrium CO2 Capture with ACTL**	Agrium's fertiliser plant in Alberta is currently being retrofitted with a carbon dioxide capture unit. Around 585,000 tonnes per annum of carbon dioxide will be captured and transported via the Alberta Carbon Trunk Line (ACTL) for enhanced oil recovery.	CANADA	Alberta
Execute	**Air Products Steam Methane Reformer EOR Project**	This project in construction will 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	Texas
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	Saskatchewan
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	Western Australia
Execute	**Kemper County IGCC Project**	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	Mississippi
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	Wyoming
Define	**Bełchatów CCS**	PGE EBSA plans to integrate a carbon capture plant into a new built 858 MW unit at the Bełchatów Power Plant. Around 1.8 million tonnes per annum of carbon dioxide will be captured (advanced amine process) and stored in deep saline formations.	POLAND	Łódź
Define	**Coffeyville Gasification Plant**	CVR Energy is developing a new compression facility at its fertiliser plant in Kansas. The plant currently produces approximately 850,000 tonnes of carbon dioxide which will be transported to the mid-continental region for use in enhanced oil recovery.	UNITED STATES	Kansas

Volume CO_2	Operation Date	Facility Details	Capture Type	Transport Length	Transport Type	Storage Type	Project URL
8.5 Mtpa	2010	Natural Gas Processing	Pre-Combustion	256 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.oxy.com/
0.68 Mtpa	1982	Fertiliser Production	Pre-Combustion	192 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.kochfertilizer.com/
3 Mtpa	2000	Synthetic Natural Gas	Pre-Combustion	315 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.cenovus.com/
1 Mtpa	2004	Natural Gas Processing	Pre-Combustion	14 km	Onshore to onshore pipeline	Onshore Deep Saline Formations	http://www.insalahco2.com/
7 Mtpa	1986	Natural Gas Processing	Pre-Combustion	190 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.exxonmobil.com
1 Mtpa + 0.2 Mtpa in construction	1996	Natural Gas Processing	Pre-Combustion	0 km	Offshore to offshore pipeline	Offshore Deep Saline Formations	http://www.statoil.com/en/
0.7 Mtpa	2008	Natural Gas Processing	Pre-Combustion	150 km	Onshore to offshore pipeline	Offshore Deep Saline Formations	http://www.statoil.com/en/
1.3 Mtpa	1972	Natural Gas Processing	Pre-Combustion	132 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.exxonmobil.com/
Up to 1 Mtpa	2013	Chemical Production	Industrial Separation	1.6 km	Onshore to onshore pipeline	Onshore Deep Saline Formations	http://www.adm.com/
0.585 Mtpa	2014	Fertiliser Production	Pre-Combustion	234 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.agrium.com/
1 Mtpa	2012	Hydrogen Production	Pre-Combustion	Not specified	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.airproducts.com/
1 Mtpa	2014	Power Generation	Post-Combustion	100 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.saskpower.com/
3.4 - 4 Mtpa	2015	Natural Gas Processing	Pre-Combustion	10 km	Onshore to onshore pipeline	Onshore Deep Saline Formations	http://www.chevronaustralia.com/
3.5 Mtpa	2014	Power Generation	Pre-Combustion	75 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.mississippipower.com/
1 Mtpa	2013	Natural Gas Processing	Pre-Combustion	370 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.conocophillips.com/
1.8 Mtpa	2015	Power Generation	Post-Combustion	51 – 100 km	Onshore to onshore pipeline	Onshore Deep Saline Formations	http://www.bot.pl/
0.85 Mtpa	2013	Fertiliser Production	Pre-Combustion	112 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.cvrenergy.com/