PCCC3

Post Combustion Capture Conference
& SaskPower CCS Symposium

Conference Summary

Regina, Saskatchewan, Canada

8th-11th September 2015

SaskPower
Powering the future®

Evaluating technology options to mitigate greenhouse gas emissions

Background

The IEA Greenhouse Gas R&D Programme (IEAGHG) Post Combustion Capture Conference (PCCC) series has established itself over its 20 year life span as one of the leading, if not the specialist, Post Combustion Capture (PCC) conference in the world. The conference provides delegates with the opportunity to listen to detailed presentations on the adavances in the current technology, development and results from major demonstration projects and next generation PCC technologies.

Delegates that attended the previous conference saw an integrated session from Technology Centre Mongstad (TCM) providing a world's first sharing of results and experiences from the first years' operation of the centre. Building on this, PCCC3 in conjunction with the 2015 SaskPower CCS Symposium, offered an unprecedented sharing of knowledge and experience at the end of a very successful year of operation of the Boundary Dam 3 CCS project. The worlds first commercial scale application of CCS in the power sector.

Technical Steering Committee

The Conference content was overseen by a Steering Committee comprising of the following members:

- Mr John Gale, IEAGHG, UK (Chair)
- Prof. Hallvard Svendsen, NTNU
- Dr. Paul Feron, CSIRO
- Prof. Gary Rochelle, University of Texas
- Prof. Paitoon Tontiwachwithikul, University of Regina
- Mr. John Lytinski, USDOE, USA
- Dr Jang Kyung-Rong, KEPCO, South Korea
- Mr. Nils Røkke, SINTEF, Norway
- Dr. Mikiaki Harada, JCOAL, Japan

Acknowledegments

IEAGHG would like to acknowledge and thank Prof. Gary Rochelle and his PhD students from the University of Texas at Austin for their invaluable input into the technical section of this summary.

THE UNIVERSITY OF TEXAS AT AUSTIN

Conference Sponsors

IEAGHG would like to thank the hosts of the event, SaskPower and the conference sponsors USDOE, JCOAL, Technology Centre Mongstad (TCM) Climate Change and Emissions Management Corporation(CCEMC) and the University of Regina. Their support has been invaluable.

Additional thanks and recognition go to SaskPower for coordinating the 2015 SaskPower Symposium and tour with the PCCC3 conference and local organisation of the IEAGHG conference.

International perspectives on PCC

To compliment the conferences technical sessions, three keynote speakers updated the audience on developments in post combustion capture (PCC) in different geographical regions; John Litynski, USDOE, Terufumi Kawasaki, JCOAL, Japan and and Roy Vardheim, TCM, Norway.

John Litynski opened the conference providing an overview of the USDOE Regulatory and R&D Efforts to Advance Carbon Capture Technologies. With coal and natural gas projected to provide 67% of energy generation over the next 25 years in the USA, CCS/CCUS is a key technology to enable the continued use of the abundance of fossil energy. The USDOE has a $6 billion climate mitigation programme with $116.6 million being allocated to carbon capture. The U.S currently has six 1st generation demonstration projects either planned or operational but is not stopping there. Looking forward to 2nd generation technologies, the USDOE has set a goal of large scale pilot validation by 2020 with transformational technology by 2025.

Having introduced the capture projects receiving USDOE funding (including the National Carbon Capture Center). John shared with the audience the pathway for technology commercialisation stating that the "valley of death" for technologies is at the large pilot scale stage. Unperturbed by this, the USDOE has selected 14 transformational capture technologies for funding this year starting with additional funding going to large scale capture projects (10+MWe). John finished his presentation by introducing the Carbon Capture Simulation Initiative (CCSI) and the work they are doing to accelerate technology development.

Extending the global picture, Terufumi Kawasaki presented the post combustion work being undertaken in Japan. With Japan's energy supply changing dramatically post Fukushima, seven new coal-fired plants are being planned although this has to be balanced with Japan's commitment to reduce GHG emissions by 26% (from 2013 levels) by 2030.

The Japanese policy on coal-related energy aims to develop plants with a much higher efficiency than used at present, accelerate cost reduction of capture technology and CCUS, develop new technologies to utilise low rank coal and contribute to global CO_2 reduction through high efficiency power generation.

In order to achieve these goals, a demonstration of CCS has been established at Tomakomai (injection to begin 2016) Japan. Intensive surveys of storage areas of the sea bed are being undertaken and CCS plans specific to Northern Japan are being initiated (i.e. shuttle ships instead of pipelines).

Terufumi shared the Japanese road maps to higher efficiency power generation and capture and cost reduction along with details of the CCS demonstration site in Tomakomai before giving detail on the progress with the different capture technologies (chemical absorption, solid absorption and oxyfuel) in Japan with the former currently being tested at Shand's test facility in Canada by Hitachi.

Instead of extensive CO_2 pipelines, Japan has been exploring the option of using small shuttle ships to transport CO_2 from the shoreline power stations to the offshore storage sites. Japanese companies supported by NEDO are also exploring an advanced oxyfuel combustion project in Alberta to include air separation units to provide CO_2 for EOR and N_2 for oil & gas sites as well as chemical plants.

Starting with a dramatic image of earth taken from space, Roy Vardheim outlined the vital role Technology Centre Mongstad (TCM) is playing in progressing carbon capture technologies not just in Norway but on a global scale.

He began by reinforcing the potential role of CCS in the energy market to reduce CO_2 emissions by 14% by 2050 but stressed that in order for CCS to be viable, the price of carbon must increase and the cost and risk must decrease.

TCM offers unique testing flexibility at an industrial scale with three operational areas and two gas feed streams provided from the NGCC power plant and refinery. Because of this facility, the TCM is able to progress CCS through testing and verification, reducing cost and risk related to scale up; develop existing full scale capture operation and contribute to scientific research and knowledge pools.

Having now completed three years of operation, TCM has conducted test campaigns, verified and increased precision for models and contributed essential knowledge for scale up design and operation. Additionally, a major contribution has been to focus global attention on the need for industrial scale testing. Regulatory experience has also progressed through the development of TCM, with learnings on permitting, environmental impacts, monitoring and solvent degradation.

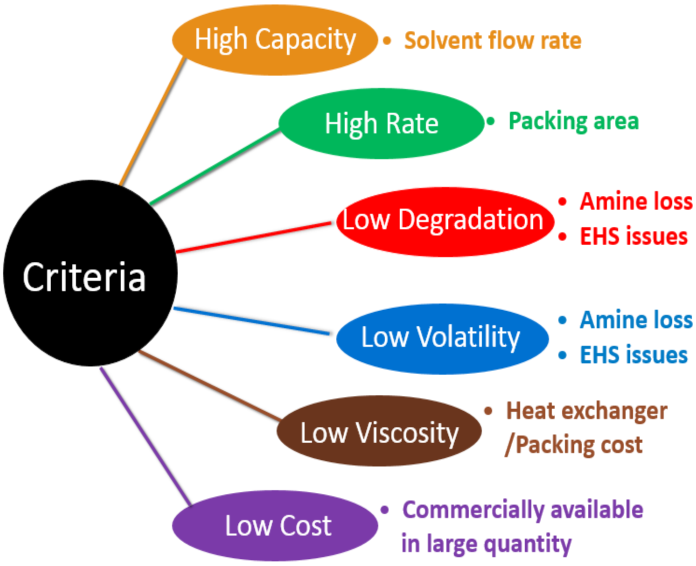
TCM is also a proud member of the International Test Centre Network having chaired from 2013-2015. The network aims to share knowledge on construction, developments, and operational experience.

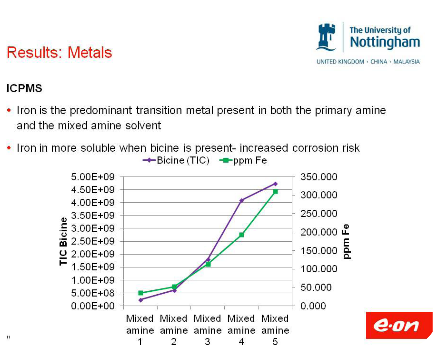
TCM's success can also be measured from its order books, with all available testing slots for both amine and chilled ammonia plants booked until 2018, the impact TCM has had on CCS globally should not be underestimated.

Audience for the plenary sessions

PCCC3 Highlights

The favoured technology for CO_2 separation from flue gases is absorption using amine based solvents. Research work to find the perfect solvent continues at a great pace with the focus on improving absorption rate, absorption capacity, solvent solubility, degradation, volatility, viscosity and heat of regeneration. A thermally stable amine 4X (4-Hydroxy-1-methylpiperidine) has been identified as a superior solvent to blend with piperazine (PZ) for flue gas CO_2 capture. Blending less concentrated PZ with 4X can remediate the precipitation issue of concentrated PZ while maintaining its high CO_2 absorption rate, and high resistance to degradation.



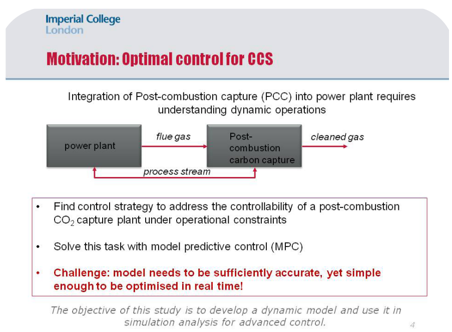


Solvent degradation and the corrosive properties of solvents can have major impacts on the cost of operating a solvent system and the performance of a solvent. These properties represent critical aspects of solvent development and screening. Current research includes detailed characterization of degraded solvents using a range of state-of-the-art analytical techniques to characterize total amine loss, specific degradation products, and the presence of metals. These techniques can be utilized to develop links between degradation products and corrosion in amine systems.

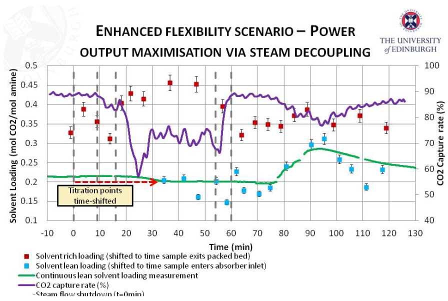
Corrosion rates of amine systems have been evaluated as a function of carbon chain length for linear amines, revealing increased corrosion with 2-carbon vs. 3-carbon chains. Research presented evaluated the use of carbon steel in place of stainless steel for certain amine systems to yield significant cost savings. Monoethanolamine (MEA) and Propylenediamine (PDA) both displayed higher levels of corrosion with carbon steel so this would need to be evaluated on a solvent by solvent basis.

The solubility of specific iron compounds was correlated to corrosivity of solvents. The presence of Fe(II) was shown to correlate well with the relative corrosion rates of MEA, Diethylenetriamine (DETA) and Methyl diethanolamine (MDEA) solvents providing the potential for a fast screening tool for solvents.

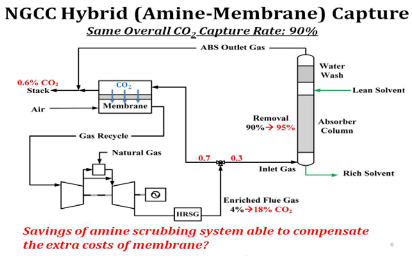
In order to demonstrate post-combustion carbon capture (PCC) at commercial scale, it is essential to understand how the laboratory and pilot scale systems will react during scale up. Multi-variable model-predictive control schemes and decentralised control schemes have been evaluated and results show that these schemes recovered quickly with minimum deviation. Based on the dynamic modelling of a supercritical coal-fired power plant integrated with PCC, researchers found that PCC systems do not have a large influence on the power plant load ramp rate, however, the coupling between the power plant steam cycle and the post-combustion system needs to be carefully designed.



Modelling has also shown that solvent inventory & circulation times have an effect on plant response and capture rate response is delayed by solvent circulation times and mixing effects. A pilot-scale study of dynamic operating scenarios for post-combustion carbon capture showed no significant barriers to flexible operation.



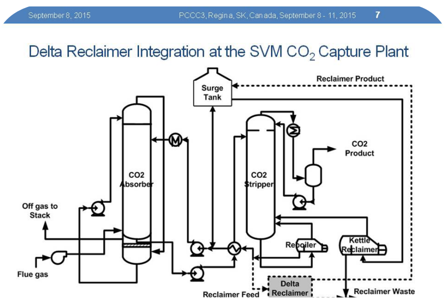
Extensive research continues into the development of novel processes and the optimization of existing processes for amine-based CO_2 capture via the use of rigorous modelling tools. Optimisation of an existing amine-based CO_2 capture plant (130 tpd) using a rigorous modelling and optimisation software package yielded significant process improvements including a reduction of the steam rate by approximately 20%, increasing the gas flow rate and changing the solvent concentration all of which can be achieved without capital expenditure. A novel hybrid process has been developed and evaluated to pair membranes with amine-based absorption-stripping process and further research is underway to identify optimal conditions for the new process configurations.



Slide presented by Y. Zhang, The University of Texas at Austin

Modelling tools can also be used to assess fundamental explanations for process performance or assess robustness of model predictions. Modelling exergy losses of an advanced stripping system revealed significant improvements in the reversibility of the absorption-stripping process by recovering heat associated with water vapour in the stripping process. Sensitivity analyses of rigorous models revealed the importance of using a consistent set of model parameters from model development through process design and scale-up.

The High Performance Capture project (HiPerCap) in the EU is developing a benchmarking and screening tool for a wide-range of post combustion capture technologies including absorption, adsorption, and membranes culminating with a technology roadmap for the most promising concepts.



Studies continue to look at the environmental and health impacts associated with flue gas emissions. Whilst the CO_2 capture process can dramatically reduce potential health risks to the nearby population through the reduction of NO_2, PM2.5 and SO_2, work must be done to prevent the release of amine aerosol components which are not removed by the use of a water wash of the absorber emissions in the gas phase.

Introduction of a specialised solvent reclaimer operation and performance in the clean-up of degraded solvents used in carbon capture from coal-fired power plant flue gas has shown excessive contaminated solvent can be restored to almost original purity with low capital and operating cost. This can help carbon capture plants to meet production capacity and clean-up targets with minimum emission to atmosphere and waste for disposal.

Where are we now and what next?

Since PCCC2 in 2013, there has been significant progress in PCC, this includes:

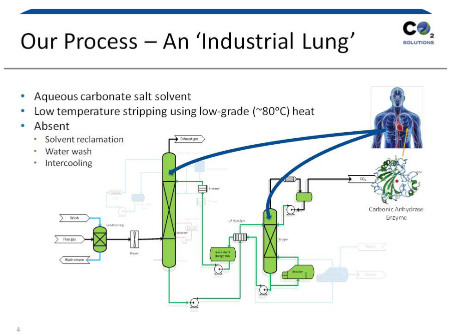
- solvent tests at TCM validating model predictions
- CO_2 capture processes now applied to numerous commercial scale plants globally
- Concentrated aqueous piperazine along with a novel advanced stripper configuration has been demonstrated to reduce energy consumption

With these learnings on board, what is next for demonstration?

- Focus on cost reduction and energy efficiency
- continue to test and prove new advanced solvents and systems

2nd and 3rd generation technology

Novel solvents have been demonstrated both in lab-scale experiments and pilot plant tests. One such development sees the use of a solvent accelerated by an enzyme, this was able to use low-grade heating with hot water at 83°C instead of steam. In comparison to amine–based CO_2 capture, the use of enzymes is expected to significantly reduce equipment footprint and capital cost with the added benefit that during initial testing, no degradation products or aerosols were generated. The next stage of testing will use rotating packed bed (RPB) in the pilot plant before moving onto large scale application and commercial rollout in 2017.



The application of novel systems using mixed-salt, chilled ammonia, carbonic anhydrase, and hybrid amine-membrane are being investigated in CO_2 post combustion systems. The technology can be enhanced not only by changing the solvent but also by improving the process flow sheet. The mixed-salt process has already been tested at a large bench-scale level, this uses inexpensive materials, does not generate hazardous waste and has demonstrated enhanced CO_2 capture efficiency with expectation that it will reduce energy consumption compared with MEA and provide a reduced cost option. A crystallizer-chilled ammonia process has been developed to avoid solid formation in a CO_2 ammonia scrubbing system. The crystallizer is used to enable a combination of CO_2 absorption at high rates and solvent regeneration at high CO_2 loading.

Investigations into immobilized enzyme carbonic anhydrase are ongoing. The enzyme is used to enhance the CO_2 absorption rate while the temperature, pH, and chemical composition of the media are controlled to maintain enzyme longevity. The membrane-solvent hybrid system is another promising novel PCC system. The membrane enriched flue gas provides a higher CO_2 concentration so that the amine scrubbing is more cost-effective.

These promising novel PCC systems increase the CO_2 absorption rate, reduce the regeneration energy penalty, and are more environmentally friendly, reducing CO_2 capture cost and energy consumption.

SaskPower CCS Symposium 2015

The PCCC3 conference was held in conjunction with SaskPower's 2nd annual symposium to encourage collaboration and knowledge sharing between the capture research community and industrial partners. The day opened with IEAGHG's General Manager, John Gale, delivering a keynote speech. John reminded the audience of why we were all gathered and the necessity for CCS in the battle to reach the 2DS target before outlining the role that SaskPower and Saskatchewan is playing in the race to see CCS deployed globally.

"Along with the United Nations and the International Energy Agency, SaskPower acknowledges that CCS is essential to realistically achieve the 2-degree goal globally."

Mike Monea, President, CCS Initiatives, SaskPower

With the scene set, SaskPower's President CCS Initiatives, Mike Monea told the SaskPower story, the how and the why's behind the decision to engineer the World's largest commercial scale capture enabled power plant. He paid tribute to the team whose determination and dedication took the project from conception to completion overcoming many obstacles along the way.

For the remainder of the morning, delegates learnt about the imperatives required to enable a project to go ahead, the need for public acceptance, requirement to be cost competitive with acceptable alternatives and the necessity to prove the technology works. The Boundary Dam CCS project has demonstrated clearly that costs can be reduced for subsequent projects, this will happen through innovation and knowledge that can only be gained from experience.

The afternoon session began with the announcement from SaskPower of the signing of a Memorandum of Understanding (MoU) with BHP Billiton to allow the development of a knowledge sharing centre aimed at accelerating the deployment of CCS through shared learning. IEAGHG then launched their report 'Integrated CCS Project at SaskPower's Boundary Dam' (2015/06) during a presentation on the report by its author Dr Carolyn Preston.

Mike Monea facing the media after the MoU announcement

Rounding off the day, presentations drilled down into the details of the first years operational experience, a look at the business case for CCS, how CCS is regulated in Saskatchewan and the role of EOR, storage and monitoring in CCS.

The main take away's from the day were:

- Not all operational objectives have been met (yet)
- The Plants performance is improving with time
- Some surprisingly good results so far;
    - Purity of CO_2 better than expected
    - 480,000 tonnes captured since operational startup

Grand CCS Tour


Arrival at Boundary Dam

Saskatchewan, as well as home to the world's first and largest commercial scale integrated CCS project of it's kind, is also home to world renouned storage and utlisation projects. To end the Conference and Symposium, it was only fitting to take delegates on a tour of these CCS facilities. Three buses with160 on board travelled the two and a half hours from Regina to the Boundary Dam Power Station in Estevan. Delegates were treated to a vitual tour of the Carbon Capture Test Facility at the neighbouring Shand Power Station (owned and operated by SaskPower) before a guided tour of both the Boundary Dam Power Plant and the CCS capture unit.


View of Boundary Dam Power Station from Aquistore site

From here attendees followed the CO_2 trail with just a short bus ride (4km) to the Carbon Storage and Research Centre (Aquistore) where experts from Petroleum Technology Reseach Centre (PTRC) gave a presentation on the injection and monitoring techniques applied at the site. Both subsurface and surface techniques have been designed and include soil and groundwater sampling as well as 3D seismic monitoring. Although now owned by SaskPower, Aquistore is run by PTRC and is the deepest well in Saskatchewan at 3396m. It has been designed for injection rates of 1600 tonnes/per day of CO_2 which will be supplied from the Boundary Dam Integrated CCS Project.


Injection head at Aquistore

The journey home took delegates through the Weyburn oil fields, home to the IEAGHG Weyburn-Midale CO_2 Monitoring and Storage Project where CO_2 is used for enhanced oil recovery (EOR). The project ran from 2000 to 2012 with the results being published in the manual *Best Practices for Validating CO_2 Geological Storage: Observations and Guidance from the IEAGHG Weyburn-Midale CO_2 Monitoring and Storage Project.*

CO_2 Capture unit, Boundary Dam

IEA Greenhouse Gas R&D Programme
Pure Offices, Hatherley Lane
Cheltenham, Glos. GL51 6SH, UK.

Tel: +44 (0)1242 802911
mail@ieaghg.org
www.ieaghg.org
www.ghgt.info