



ghgt-14

GHGT-14 summary

14th International Conference on
Greenhouse Gas Control Technologies



21–25 October 2018

Melbourne Convention and Exhibition Centre
Melbourne, Australia



National Gallery of Victoria, Melbourne
Venue for the GHGT-14 Welcome Reception



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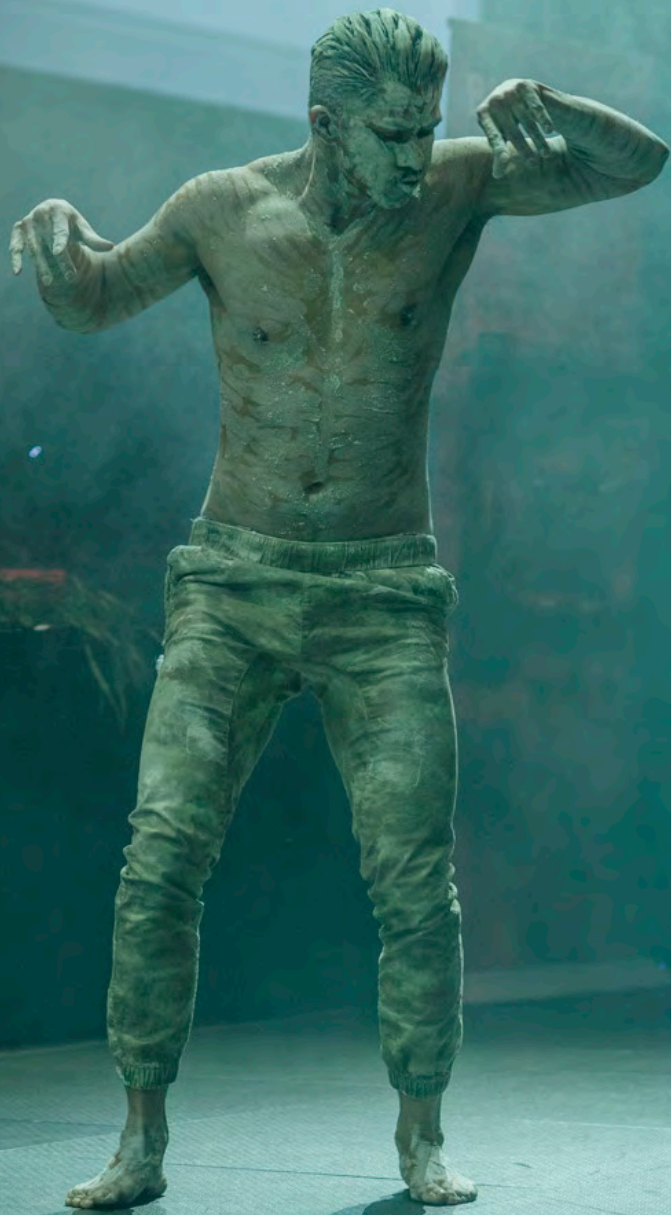
The GHGT-14 Summary Brochure was Written by James Craig and colleagues at IEAGHG with significant contributions from the Technical Programme Committee. IEAGHG would like to thank all contributors for giving their time to this publication.

Welcome to Country - Traditional Dance





ghgt-14 BHP



SPONSORS

IEAGHG would like to thank all of our GHGT-14 Sponsors for their generous contributions which helped support a very successful conference

GOLD SPONSORS

The BHP logo consists of the letters "BHP" in a bold, orange, sans-serif font.The CarbonNet Project logo features a stylized graphic of three overlapping triangles in green, blue, and purple, followed by the text "CarbonNet Project" in a black, sans-serif font.The ExxonMobil logo features the word "ExxonMobil" in a red, sans-serif font, with a stylized red "X" that incorporates a white diagonal line.The GASSNOVA logo features a stylized graphic of a cluster of blue dots of varying sizes, arranged in a shape reminiscent of a gas molecule or a star, above the word "GASSNOVA" in a blue, sans-serif font.The Kawasaki logo features a red stylized "K" symbol, followed by the word "Kawasaki" in a red, sans-serif font.The TOTAL logo features a stylized graphic of a globe with red, blue, and yellow segments, followed by the word "TOTAL" in a red, sans-serif font.

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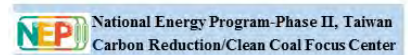
Welcome Reception



Conference Bags



Student Reception



Conference Lanyards



Conference Signage



Conference Signage



GHGT-14 BACKGROUND

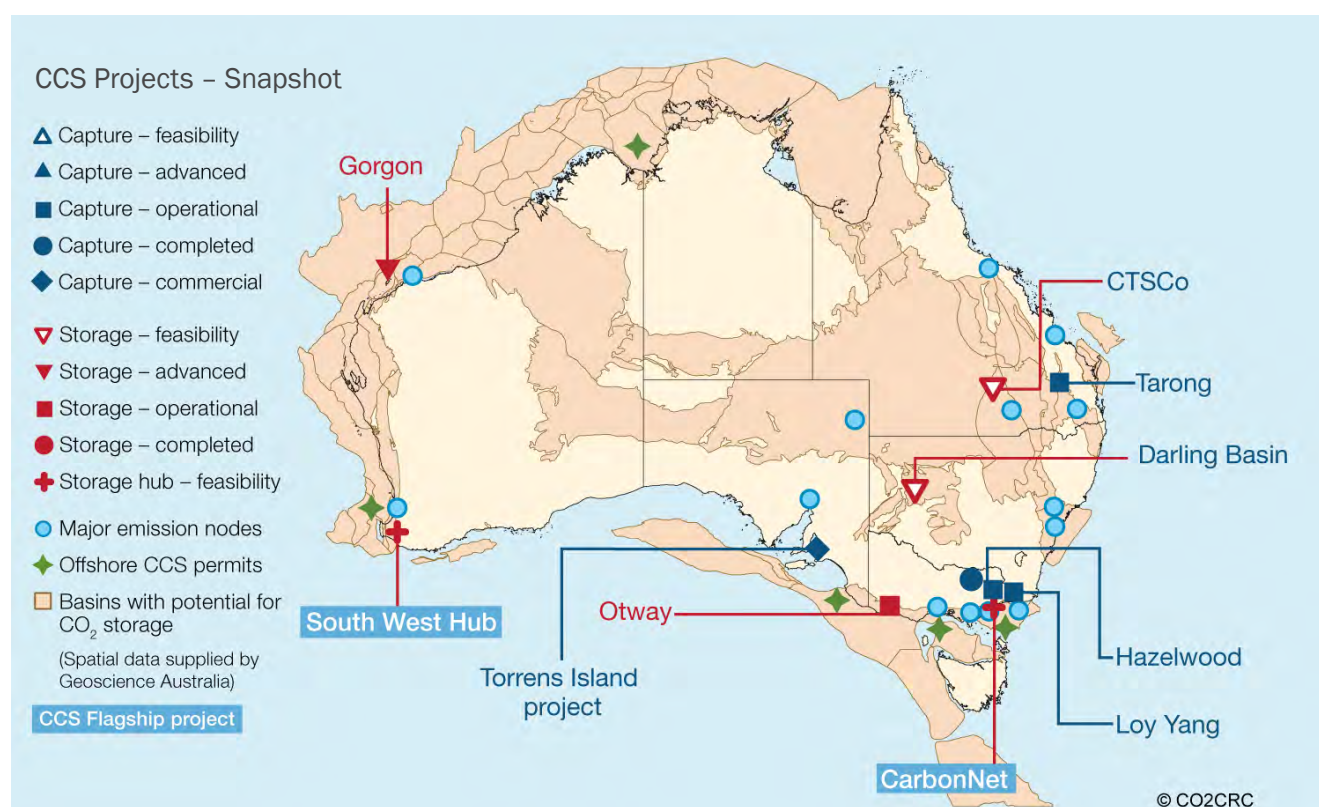


Australian Government
Department of Industry,
Innovation and Science

Australia is at the forefront of CCS research, development, with supportive scientific investigation and is now gearing-up for commercial-scale deployment through the CarbonNet project and the Gorgon CO₂ Injection Project. This influential work on all aspects of CCS was well represented throughout the conference plenary, panel and technical sessions. Australia is a resource-rich country especially in fossil-fuels and minerals. Australia continues to invest in new technologies and approaches, especially to deliver better environmental outcomes, along with other priorities, to maintain a competitive resources sector.

Beyond the CarbonNet and Gorgon CO₂ Injection projects, other important initiatives include those facilitated by the Australian Government's RD&D Fund (2016-2019) which is supporting a number of commercial and research entities to reduce the technical and commercial barriers to the deployment of large-scale CCS projects.

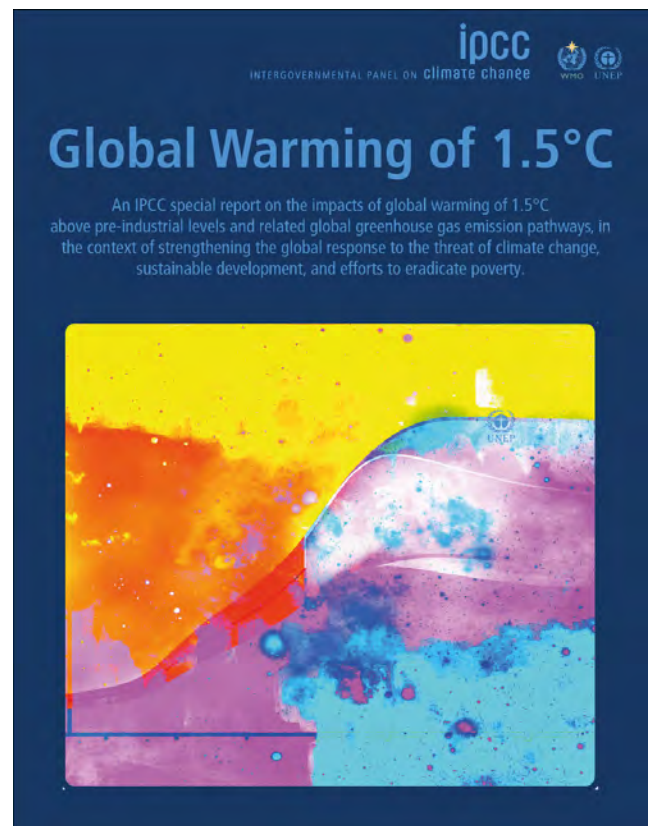
Low and zero emission hydrogen markets are also envisaged to play an important role in commercialising low emission technologies such as CCS, when hydrogen is developed from fossil fuels. For example, the Hydrogen Energy Supply Chain is a world-first pilot project to safely and efficiently produce and transport clean hydrogen from Victoria's Latrobe Valley to Japan; a commercial scale operation will require CCS services such as those being developed by the CarbonNet project.



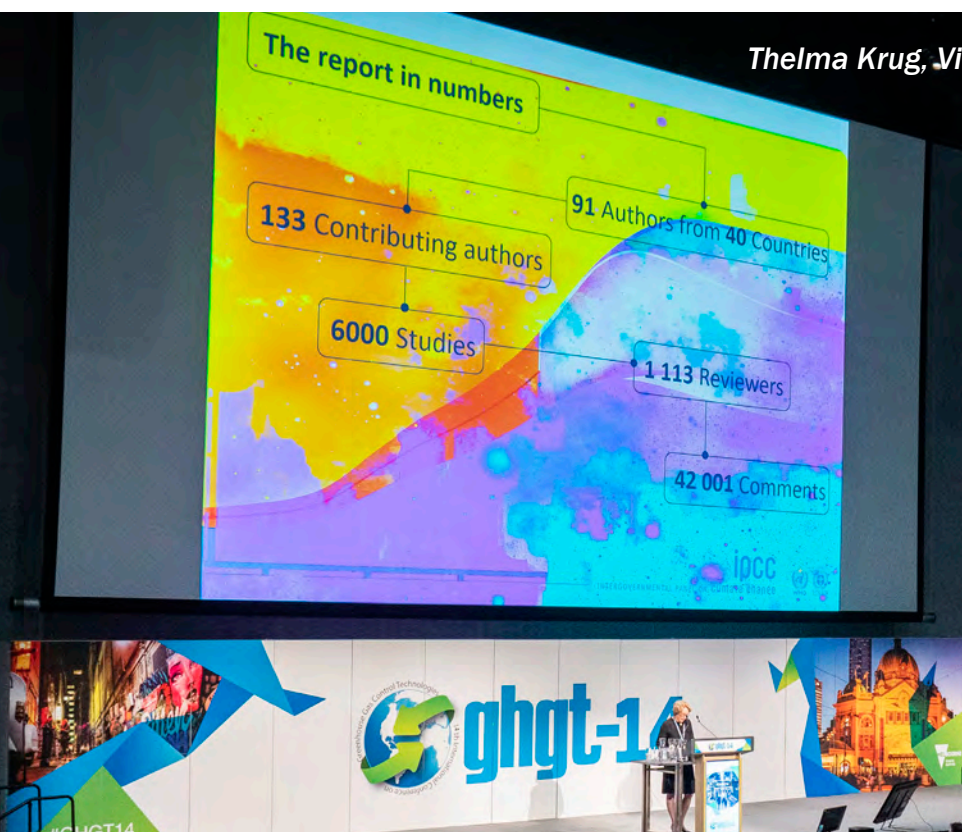
GHGT-14 BACKDROP

The GHGT-14 conference opened soon after the Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5°C was published. The key conclusions from this latest IPCC report have highlighted the scale of carbon emission reduction that needs to be achieved by mid-century to avoid potentially catastrophic climate change. Growing evidence, in the form of heat waves across the northern hemisphere in 2018, and an increase in the number and frequency of other extreme weather events such as hurricanes, is indicative of climate change.

The challenge faced by the modern industrialised economies, and particularly the rapidly growing economies of the developing regions of Asia, Africa and the Americas, is how to balance the energy and resource demands to meet the aspirations of the global economy whilst avoiding deleterious environmental impacts. IEA projections based on technology assessments of carbon emission options show that CCS, in combination with other low carbon technologies, has a key role in meeting the below 2°C target (B2DS). Despite the growth and success of renewables for electricity generation, most primary energy is still derived from fossil fuels especially for transport, heat and many industrial processes. CCS in particular can address carbon emissions from industry such as process emissions from iron, steel, cement and the petro-chemical sector. The prospect of developing a hydrogen based economy, linked to CO₂ storage, also offers a very real, and practical, alternative to the conventional use of fossil fuels. This was a major theme of the GHGT-14 conference which highlights the genuine investment of leading industrial companies in the CCS – H₂ supply chain.



Thelma Krug, Vice Chair of the IPCC



GHGT-14 STATISTICS



1012 Delegates from 31 Countries



352 Oral Presentations



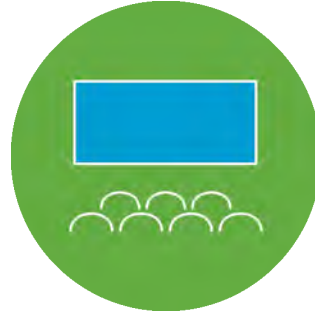
4 Keynote Speakers
9 Technical Plenaries



12 Themes
116 Sub-Themes



143 Reviewers



71 Technical Sessions



7 Panel Discussions



430 Posters



1074 Abstracts
Received



20 Side Events



GHGT-14 EXHIBITION

GHGT-14 featured an enhanced exhibition. Gone were the “shell scheme” stands of previous years, replaced by premium custom stands. A record 18 CCS projects and organisations from around the world chose to exhibit in the newly opened extension to the Melbourne Convention and Exhibition Centre. Catering was served amongst the stands allowing delegates to look around the exhibition whilst eating lunch and during breaks.



SETTING THE SCENE – KEY POINTS FROM PLENARY SESSIONS

The recurrent theme of GHGT-14's Plenary Sessions, was the impending impact of climate change and a series of initiatives by leading countries specifically Australia, Norway, Japan, the USA and China to develop CCS across the supply chain.

The recently-published special report on global warming of 1.5°C set the scene. Its key findings were presented in the opening plenary by Thelma Krug, IPCC Vice-Chair. Drawing on more than 6,000 studies, 91 authors from 40 countries it considered the impact of a 1.5°C rise in temperature above pre-industrial levels, and presented potential pathways to limit global warming accordingly by 2100. Ms Krug pointed to findings that showed a 2°C rise rather than 1.5°C would lead to extreme warming, rain and aridity, with melting of ice sheets and glaciers resulting in substantial rises in sea levels. To achieve a reduction of 45% in 2010 CO₂ emissions levels by 2030, and reach net zero by 2100, would require a concerted effort where CCS and CO₂ Removal (CDR) would play crucial roles. Of the four modelled pathways presented in the report, a pathway without CCS or BECCS was potentially not feasible. Thelma Krug expressed the hope that at least some of the current knowledge gaps would be resolved for inclusion in the IPCC's 6th Assessment Report due for publication in 2021.



Laszlo Varro, the IEA's Chief Economist, emphasised that policy and financial innovation was equally as important as technical innovation, and that progress in all three would be necessary to underpin the broader deployment of CCS. He stressed that the principal energy medium for the 21st century would be electricity as direct use of fossil fuels become displaced. CCS would play a major role in providing the low-carbon electricity required. Although coal use has been declining in Europe and the USA it is still the single largest energy source for global electricity generation. In contrast, in



Asia more than 650 GW of coal-fired generation plant is less than 10 years old, much of it appreciably more efficient than the best performing US plant. This is particularly significant when IEA scenarios show that CCS could contribute 32% of the cumulative CO₂ emissions reductions by 2060 compared with business as usual. This contribution is contingent on reaching some extremely ambitious goals related to the decommissioning of coal plants and the reduction in load at those that remain.

The role of prominent industrial companies in CCS development was exemplified by BHP's Vice President Sustainability and Climate Change, Fiona Wild. She emphasised BHP's ambitious goal to reach net zero emissions by 2050. To illustrate her premise that more could be achieved collectively with other stakeholders, she described BHP's many collaborations with organisations in a range of countries, including their joint effort with SaskPower in setting up the International CCS Knowledge Centre in Regina, Saskatchewan. However, policy support was essential and governments still have a vital role to play, along with the setting of a market-based carbon price.



Jérôme Schmitt, a senior executive at Total and Chair of OGCI's Executive Committee, opined that CCS was more about cooperation than about competition. He emphasised that CCS was a business which needs to make money and create value otherwise it cannot proceed. Jérôme proposed the establishment of new degrees in carbon management. In closing remarks he stressed the necessity for governments to act collectively if CCS was to play its role in addressing climate change.



Other plenary contributors announced a series of initiatives that various governments, prominent corporations and organisations are actively engaged in. These include:

Flagship projects that include the Air Products capture plant at the Valero oil refinery in Port Arthur, Texas.

The Petra Nova site post-combustion capture plant, linked to a CO₂-EOR operation, also in Texas.

The ADM ethanol plant in Decatur, Illinois that injects CO₂ into a saline aquifer.

The introduction of the 45Q tax credit initiative that is stimulating genuine interest in CCS investment in the USA.

Setting-up the EDX energy data exchange and support for newer, smaller (50-350 MW) coal-fired power plant adapted for load-following generation that is better suited to integration with the rapidly expanding intermittent renewables power generation. Steve Winberg from the US Department of Energy observed that the current capture costs of \$US80 -100 tonne need to hit \$US30 a tonne.

The development of an energy supply chain based on hydrogen in Japan as part of a national ambition to reduce national CO₂ emissions by 80% by 2050.

The development and demonstration of a pilot-scale system based on the innovative Allam Cycle capture technology in natural gas based combined cycle power plants. Bill Brown from Net Power explained how the technology could lead to very significant reductions in capture costs and lead to commercially attractive income from the onward sale of CO₂, N₂ and Ar as by-products.

Anthony Ku of China Energy's research, development and demonstration (RD&D) arm, the National Institute of Clean and Low-Carbon Energy (NICE), described the steps taken by China to reduce emissions with ambitious commitments to reduce its GHG emissions by ~65% below 2005 levels by 2030.

Dr James Johnson, CEO Geoscience Australia, highlighted the significant investments made by the Australian Government to reduce the technical and commercial barriers of CCS. The Australian Government, in partnership with industry and researcher organisations, is supporting a range of research, demonstration and deployment activities such as the CO2CRC Otway Research Facility and the commercial scale Gorgon CO₂ Injection Project.

Operations at the US National Carbon Capture Center (NCCC) in Alabama are truly international, with technologies from six countries other than the United States having been tested. NCCC has developed close ties with China and India and, in a partnership with Norway's Technology Centre Mongstad (TCM), has been instrumental in the establishment of the International Test Centre Network (ITCN).

The Hydrogen Energy Supply Chain (HESC) project, highlighted by Richard Bolt from the Victorian Government, will gasify lignite (brown coal) mined in the La Trobe Valley to produce hydrogen via reformation. The CO₂ produced from the process would then be transported and stored by CarbonNet in highly favourable geological formations within the Gippsland Basin. This collaborative project led by Kawasaki Heavy Industries (KHI) can provide Japan with liquefied hydrogen shipped to the port of Kobe. The CarbonNet project is making good progress with offshore appraisal and development well underway.



SPONSORS' LUNCH

To thank the GHGT-14 sponsors a special lunch was arranged. Sponsors were given an introductory talk from Professor Kelly Thambimutu FTSE, Chair of IEAGHG Executive Committee and a Co-chair of the conference and a guest presentation by the Chief Scientist of Australia, Professor Alan Finkel AO FAA FTSE. Professor Finkel gave a highly illuminating presentation from outside the sector on the future of the hydrogen economy and the significance of the role of CCS.



RESEARCH AND DEVELOPMENT ACHIEVEMENTS – KEY HIGHLIGHTS

- Advances made at the Otway site and at Aquistore in Saskatchewan have demonstrated the effectiveness of buried seismic monitoring arrays which can reduce acquisition time, cost and the impact on landholders, while increasing data quality and repeatability.
- The massive leap forward in the development of the Allam Cycle for natural gas, moving from what was a concept less than 10 years ago to a Technology Readiness Level (TRL) of 8-9 today. The claimed power cost (with capture) is lower than a reference system using the same fuel.
- The increased number of emerging capture technologies (i.e. solid sorbents, calcium looping, polymeric membranes) demonstrated at large pilot level (TRL6-7) in post-combustion applications. Good work was also presented on alternative solvents with a strong focus on lean water solvents.
- Experimental work on some capture technologies indicates high corrosion rates at relatively low levels of impurities (between 10 and 85 ppmv level of SO₂, NO_x & O₂). A better understanding of the impact of different types of combined CO₂ flows (i.e. with impurities) on the transport network (e.g. corrosion) is required.

CCS DEPLOYMENT AND GEOLOGICAL STORAGE OF CO₂

During the conference, the GHGT-14 delegates were given updates on the status of a number of CCS demonstration projects that were underway at the time of the conference. Projects included:

> **Boundary Dam 3 and Aquistore**

Boundary Dam 3 and Aquistore, completed in 2014, has transformed the aging Unit #3 at Boundary Dam Power Station near Estevan, Saskatchewan, Canada into a reliable, long-term producer of 120 megawatts (MW) of base-load electricity that can also reduce greenhouse gas emissions by up to one million tonnes of CO₂ every year.

The capture plant has faced technical challenges. Firstly there were process complications associated with fly-ash and other contaminants. Significant levels of amine solvent degradation also occurred. Between October 2015 and August 2017, major work was undertaken to rectify these issues and replace some carbon steel infrastructure with stainless steel. Other improvements have included anti-fouling measures. As a consequence of these enhancements, SaskPower has demonstrated that an operation design capacity of 3,240 tonnes per day, and the ability to maintain 85% operational availability, were achieved by the end of 2017.

Boundary Dam also has a direct link to Aquistore where significant progress in CO₂ injection and storage has also been made. Since its start-up Aquistore has faced some challenging conditions particularly the intermittent supply of CO₂ to the storage site. The bulk of the CO₂ is sold to an oil operator for EOR. The resultant irregular injection volumes have led to interesting reactions from the reservoir. Despite these conditions good models have been verified by history matching the injection data. The highly saline nature of the formation brine has led to salt crystallization issues in the wellbore. Lessons learned at a harsh environment like Aquistore can be applied to CCS projects throughout the world.

Even greater savings have been projected based on preliminary designs for a technology scale-up at SaskPower's Shand Power Station. This new plant will have a capture capacity of 2Mt/year, double that of Boundary Dam 3 (BD3). Operational flexibility is a key feature of the system design which will enable efficient integration with the grid, including intermittent load fluctuations that can occur with renewable energy supply for example. Other technical advances include zero liquid discharge and dramatic cost reductions by as much 92% in the capital cost of power plant per installed megawatt and as much as 67% in the capital cost of capture plant (per tonne of CO₂ captured).

> Quest

Quest captures CO₂ from a hydrogen production facility in Alberta, Canada. It is piped 65 km and injected into a highly permeable formation, the Basal Cambrian Sands. By mid-2018 this highly successful project had stored more than 3 million tonnes in 32 months of operation with excellent injectivity. Multiple technologies used to monitor, measure and verify (MMV) indicate that the CO₂ is where it is expected to be. Moreover only 2 wells have been required and operating costs are lower than expected. Microseismic monitoring has revealed very low magnitude events and do not represent a risk to containment.

> Tomakomai

The Tomakomai CCS Demonstration Project in Japan is injecting CO₂ from an off gas source in an oil refinery located near the port. CO₂ is injected from the shore via two deviated wells into two reservoirs (the sandstone Moebetsu Formation 1,000 - 1,200m and volcanoclastic Takinoue Formation at 2,400 - 3,000m). The site is actively monitored especially for seismic activity so that any natural events can be distinguished from induced seismicity that may be caused by CO₂ injection. Between February and November 2017, 100,000 tonnes had been injected into the higher reservoir and no seismicity was detected. Test injection into the deeper Takinoue formation started in early 2018.

> The Illinois Basin – Decatur Project

The Illinois Basin – Decatur Project (IBDP) is a one million tonne deep saline geological CO₂ storage project led by the Midwest Geologic Sequestration Consortium (MGSC). IBDP was a fully integrated demonstration project located on the Archer Daniels Midland (ADM) Company bioethanol plant in Decatur, Illinois, USA. Storage is in the Mt. Simon Sandstone, a saline reservoir in the Illinois Basin. The project is currently in a post-injection monitoring phase. An extensive Monitoring, Verification, and Accounting (MVA) program has been undertaken for the IBDP. It is focused on the 0.65 km² (0.25 mile²) project site. Multiple environmental monitoring networks have been established to demonstrate that long-term storage of the injected CO₂ is effective and that human health and the environment can be protected.

A successor project was initiated in 2017 which built on the earlier demonstration CO₂ capture and injection at the Decatur site. This more advanced stage is being developed under the umbrella of the Illinois Industrial Carbon Capture and Storage (IL-ICCS) project. In addition to an annual injection rate of 1 Mt CO₂ a new monitoring well was successfully recompleted during May - June 2017. Operation with the new system is now scheduled to continue through the injection and post-injection monitoring periods of the IL-ICCS project to approximately 2032.

> Otway

Otway in Victoria was the first site in Australia to demonstrate safe storage of CO₂. There has been extensive research work with Australian and international industrial and academic partners to develop and improve processes, reduce uncertainty, and decrease the cost of CCS. Achievements to date have included: the safe storage of 65,000 tonnes of CO₂ rich gas in a depleted methane reservoir; management of uncertainty and risk in CO₂ storage; the development of sophisticated modelling tools to predict CO₂ movement within a saline formation; and the use of time-lapse monitoring equipment to detect as little as 15,000 tonnes of CO₂ stored at 1,500m. CO₂ separation from a natural gas (CH₄ rich) extraction well using adsorbents and membranes has also been achieved in a high-pressure gas flow environment.

> **CarbonNet**

The CarbonNet project has already identified and gained legal access to CO₂ storage sites within the Gippsland Basin in Victoria, Australia with over 25 years capacity which equates to 125 million tonnes. The Pelican storage site is within 20 km of the coast of Victoria, SE Australia and it is formed from some of the same reservoirs and seals that have been used to produce hydrocarbons. 50 years of oil and gas activity in the Gippsland Basin has allowed CarbonNet access to a vast amount of 2D and 3D seismic data.

> **Petra-Nova**

This is a joint venture in Texas, USA between the power generation company NRG and JX Nippon, to install and operate a post-combustion CO₂ capture plant on a coal-fired power plant. Captured CO₂ is piped to the West Ranch oil field southwest of Houston. The project received a \$190 million U.S. Department of Energy grant. Petra Nova became operational on 29th December, 2016. Within the first 10 months, the plant delivered more than 1,000,000 tons of captured CO₂ and boosted oil production by 1,300%. It has been estimated that 25-30% capital cost savings could be achieved on a second-of-a-kind plant by rationalising design and reducing redundancy. In the United States a combination of enhanced 45Q tax incentives, with standardised design, could well have a very positive impact on the cost of a new CCS plant.

> **Port Arthur**

Port Arthur is a CO₂ capture demonstration project within the Valero refinery in Texas, USA. The site produces hydrogen, steam and power and has a vacuum swing adsorption (VSA) CO₂ capture system that supplies the gas to the West Hasting oil field for EOR (Enhanced Oil Recovery). The technology has achieved a 90% capture rate equating to 1 million US tons of CO₂ per year. The US DOE funded 66% (\$284 million) of the \$430.6 million total cost for this demonstration project.

Notable achievements and valuable experience has been gained. The new VSA capture technology has been commissioned and operated successfully under tight time constraints with a skilled technical team. The engineering scale-up factor of capture technology was remarkable at 27,000:1. This site has been in operation for more than a century. It is complex and required considerable ingenuity to achieve successful installation without adverse impacts on existing operations.

> **Carbon Transport and Storage Company (CTSCo)**

The Carbon Transport and Storage Company (CTSCo) is developing a ~200,000t integrated CCS storage initiative via their Surat Basin CCS project in Queensland, Australia. The project aims to build confidence that CO₂ can be safely stored for large scale storage in the future. The feasibility and front end engineering and design (FEED) work has been supported by the Australian Government, the Australian black coal industry via the COAL21 Fund and the Australian National Low Emissions Coal R&D initiative. Significant Post Combustion Carbon Capture (PCCC) design work has been undertaken by the Huaneng (China) Clean Energy Research Institute. CTSCo continues to consult closely with the local community.

POST-COMBUSTION CAPTURE (PCCC)

Significant advances have been made in a number of key areas to meet the challenges posed by high-temperature degradation of amines, the high-costs for retrofitting existing power and chemical plants, and the high operational costs for carbon capture advanced configurations, either by themselves, or combined with novel solvents.

There have been a number of notable collaborations in PCCC technology development related to novel or improved solvent formulation and advances in capture plant design and configuration. Examples presented included:

- Joint development by Mitsubishi Heavy Industries (MHI) and Kansai Electric Power Co., Japan of a new absorption solution and enhanced CO₂ capture process that exhibits a higher stability and lower amine volatility while maintaining superior capture efficiency than the KS-1™ solvent.
- Micro-encapsulated sorbents (MECS), a combination of both liquid solvents and solid sorbents, were tested for longevity, CO₂ capacity and CO₂ absorption rates.
- A techno-economic assessment of typical water-lean solvents and a cost-benefit comparison with typical aqueous amine solutions for coal-fired power plant flue gas conditions to reduce water content and reboiler energy demand.
- CSIRO, Australia have partnered with IHI Corporation of Japan to reduce the cost of amine based absorbent technology. CSIRO Absorption Liquid 008 (CAL008) has been tested as part of the PICA project at AGL Loy Yang Power Station in Victoria's Latrobe Valley and assessed against the baseline amine absorbent, monoethanolamine (MEA).
- RTI International (an independent research institution based in North Carolina, USA) and SINTEF have been engaged in the advancement of RTI's non-aqueous solvent (NAS) technology that captures CO₂ from flue gases.
- The CANSOLV (a Shell Global Solutions subsidiary) CO₂ capture process has been demonstrated via 10,000+ hours of pilot operation and is being commercially deployed at various locations around the world, including at the Boundary Dam 3 coal-fired power generation unit in Saskatchewan, Canada. A status update of the latest advancements in this capture process and, more specifically, on the improvement with high pressure regeneration was presented.
- Recent developments by CSIRO, Australia on aqueous ammonia-based capture processes were presented, along with results obtained from the pilot plant trials at Vales Point power station in New South Wales.
- Technological innovations on PCCC covered rotating packed beds (RPBs), which are an intensified alternative to conventional gas-liquid contacting columns, and pre-concentrating membranes. The enrichment of CO₂ in the flue gas by the membranes provides an increased CO₂ load and therefore greater capture efficiency.
- Regenerative chemical absorption processes based on the development of new blended solvents, including CO₂ solubility in various concentrations of aqueous piperazine and polyalkylated imidazoles.
- Other research challenges presented at the conference included solvent formulation development to reduce viscosity.

There have been a number of notable collaborations in PCCC technology development related to novel or improved solvent formulation and advances in capture plant design and configuration.

Solvent Degradation

Oxidative degradation and loss of aqueous amines during PCCC at coal-fired power station flue gases remains a significant problem. Important outcomes of amine degradation research included the rapid identification and quantification of degradation products, measurement of various reaction rates and the effectiveness of various inhibitors.

Other advances have been made on a model validated against results from several pilot capture plants that could then be used to predict results from other pilot plants. Combined capture of SO₂ and CO₂ has been trialled, as has been the development of countermeasures to reduce amine mist.

Results from Technology Centre Mongstad (TCM), Norway

- An MEA-based test campaign, initiated in 2015 at TCM, was revisited in early 2018 to investigate further potential for both CAPEX and OPEX reduction. Other research has focused on corrosion and evaluation of resistant materials that can tolerate full-scale operating conditions.
- In 2017, TCM executed a series of test campaigns to capture CO₂ from a Residual Fluid Catalytic Cracker (RFCC) refinery flue gas in “first of its kind” test campaigns.

Post-Combustion Process Modelling

- Initiatives included simulations of selective exhaust gas recirculation (S-EGR) linked to the flexible operation in CO₂ capture plants at different scales. Other modelling work presented at GHGT-14 covered control strategies for capture plant integrated with flexibility operated coal-fired power plant.
- Several modifications to the steam cycle configuration at the Shand coal-fired power station in Saskatchewan, Canada were evaluated in order to investigate the effects of additional stages.

CCS FOR INDUSTRIAL SOURCES

Several examples of CCS linked to industrial sources were presented, including:

- Estimates of CAPEX and OPEX costs, using a global energy-economic model, for capture plant deployed at sectors including iron and steel, cement, refineries, ethanol and ammonia.
- The EU's Accelerating CCS Technologies (ACT) initiative. The participants of ALIGN-CCUS, which commenced in September 2017, represented the ERA-NET ACT countries of the Netherlands, Germany, Norway, Romania and the United Kingdom.
- Results from the EU CO2stCap project, which investigates how the cost of CCS is affected by partial CO₂ capture and technological optimisation for different industries. Case studies included cement, pulp and paper, and silicon production facilities for solar panels, and also a steel mill.
- Comparisons at a CEMCAP reference kiln of five different capture technologies for CO₂ capture, including calcium looping, membrane technology assisted with liquefaction, chemical absorption, chilled ammonia and oxyfuel. The primary objective of CEMCAP is to prepare the ground for large-scale implementation of CO₂ capture in the European cement industry.
- Other examples included PCCC using amine absorption applied to Combined Heat and Power (CHP) plants.



STORAGE MONITORING

- seismic imaging provides the primary means of tracking the distribution of CO₂ within storage reservoirs. The depth of the reservoir, and the relatively small quantities of CO₂ injected, can pose a serious challenge for imaging a CO₂ plume. 3D VSP surveys have been conducted using a fibre optic cable permanently cemented on the outside of the observation well casing. The good-to-excellent repeatability of the data acquired using permanently installed sensors provides the sensitivity to map CO₂-related amplitude differences for depths of >3,200 m depth. Clear time-lapse amplitude anomalies associated with the CO₂ plume in the Aquistore reservoir have also been observed.
- The time-lapse change induced by pressure-tomography is another technique which is planned to be tested at Otway to monitor plume movement. The technique needs to be developed further so that it can operate on a scale of hundreds of metres in order to detect and locate CO₂ plumes.
- Distributed acoustic sensing (DAS)-based vertical seismic profile (VSP) and distributed temperature sensing (DTS) are also being tested for imaging CO₂ injected during enhanced oil recovery (EOR), at a site in Michigan. The quality of the baseline DAS VSP has been deemed sufficient to use as a reference for future repeat VSP surveys.

> Quest, Canada

Microseismic monitoring is a key component of the Quest MMV Plan to ensure the continued assessment of that risk and to provide early notice of any changes. Since January 2017, sustained low level, small magnitude 2 microseismic activity has been observed within the Quest area of review (AOR) which extends 10 km radially outwards from an active injection well. More than 100 locatable events were recorded in 2017, with an average magnitude of -0.7, a maximum magnitude of 0.1 and with a typical occurrence rate of 1-2 events per week. Microseismic activity at this level does not present a risk to containment.

> Tomakomai, Japan

At the Tomakomai storage site, which is just offshore, an ocean bottom cable (OBC) system has been deployed to monitor natural seismicity. An advanced monitoring technology, using distributed fibre-optic sensing (DFOS), is also being used to monitor geomechanical (stress) responses during CO₂ injections in Mobara, Japan.

> Decatur, USA

The workflow includes a newly developed tomography (a technique for creating a series of sequential images or sections through the use of penetrating waves). This technique is integrated with microseismic, 3D seismic and VSP (vertical seismic profiling) data. Observed clusters of microseismic events are consistent with a pressure-induced triggering mechanism and can be explained by lateral heterogeneity within the reservoir.

> Northern Lights – Large-Scale Storage Offshore Norway

The Measurement, Monitoring, and Verification (MMV) program for the Northern Lights project must conform to Norwegian regulations established in 2014 to ensure conformance (understanding of CO₂ behaviour), containment (ensuring the CO₂ migration is controlled) and contingency (detecting and addressing significant anomalies and leakages). A mix of several monitoring methods have been proposed to address these objectives including seismic techniques.

> Petra-Nova, USA

A monitoring and accounting process is demonstrating that a large volume of CO₂ (up to 1.6 MMT/year) captured at the coal-fired W.A. Parish Plant (Petra-Nova) is effectively stored as part of a CO₂ EOR operation at the West Ranch oilfield in the Gulf Coast of Texas. The approach to monitoring and accounting is based on previous US DOE-funded research-oriented monitoring programs. Major advances in monitoring approaches in this project are designed to optimize data acquisition at minimum cost.

> Otway and Aquistore Dedicated Sessions

At the CO2CRC Otway Research Facility in Victoria the use of distributed acoustic sensing (DAS), combined with permanent surface orbital vibrators (SOVs), to acquire seismic data at relatively low cost, has been tested. PTRC (Saskatchewan) Aquistore's permanent seismic array, installed over 6 km², is used as a time-lapse measurement tool to optimize the subsurface seismic image and its repeatability between the pairs of 3D seismic data sets. JOGMEC (Japan Oil, Gas and Metals National Corporation) has also used this site to test their orbital permanent source. The inherent robustness, affordability, and the permanent installation of acoustic receivers that use fibre optic cables, shows that the technique is becoming significantly more economically viable compared to conventional seismic sensors.



MINERAL TRAPPING

- Carbonation caused by reactive CO₂ in Basalt is attracting continued interest. The same reactive principle is being applied to carbonation in waste concrete and could improve its quality for re-use. In the current work, the dissolution kinetics of waste concrete was experimentally measured and compared to a physical model. Additionally, experiments were performed that demonstrate the feasibility to mineralize waste concrete particles under flue-gas conditions.
- Mineralization in volcanic-sedimentary reservoirs is also under investigation as part of global assessments of CO₂ storage capacity, since this may expand both the volume and geographic distribution of possible storage reservoirs.

STORAGE CAPACITIES

There are a number of initiatives world-wide to evaluate large-scale storage capacities:

- The potential sites will be selected from offshore areas in Japan with capacities of over 100 million tonnes of CO₂.
- Norwegian interest is focused on the Utsira formation used for Sleipner storage and the Northern Lights Project.
- Australian research is exploring the offshore Gippsland Basin in Victoria and the onshore Surat Basin in Queensland.
- The US Regional Carbon Sequestration Partnerships (RCSPs) continue to evaluate storage potential linked to EOR, and, in the case of the Illinois Basin-Decatur project, storage in a deep saline formation.

CO₂-EOR

There were several presentations covering the topic of CO₂-EOR and the technique's link to CO₂ storage. Although the USA dominates, several countries have potential or are investigating CO₂-EOR prospects including Australia, Argentina, Brazil, Canada, China, Colombia, India, Indonesia, Mexico, the Middle East (Saudi Arabia, UAE, others), and the North Sea (Great Britain and Norway). More detailed papers covered actual examples including:

- The giant Lula oil field, offshore Brazil, that involves capture of CO₂ from associated natural gas production.
- The Abu Dhabi Company for Onshore Oil Operations (ADCO) and the Abu Dhabi Future Eenergy Company (MASDAR)-sponsored CO₂-EOR project in the Middle East in the Rumaitha oil field, that involves capture of CO₂ from an Emirates Steel plant in Abu Dhabi.
- Saudi Aramco's CO₂-EOR project in the Uthmaniyah (Gawar) oil field in Saudi Arabia.
- Fields in the Norwegian sector of the North Sea have been screened and three were selected for more detailed scrutiny.
- Experience from over 40 years' of CO₂-EOR operations in the US can offer valuable insights into the likely behaviour of large scale CO₂ storage. The RCSP plan covers design and implementation of demonstration studies of CO₂-EOR to assess CO₂ behaviour and quantify capture rates.
- Other studies have investigated the potential for CO₂ storage in Residual Oil Zones (ROZs). The U.S. Geological Survey (USGS) is preparing a national resource assessment of the potential hydrocarbons recoverable after injection of CO₂ into conventional oil reservoirs in the United States which will be compiled into a comprehensive resource database and will include proprietary technical information.

NEGATIVE EMISSIONS

The focus on negative carbon emissions at the conference focused on the use of biofuels combined with CCS (BECCS). Different aspects of this concept were explored including:

- Modelling to optimise the BECCS supply chain which is dependent on which metric – land, water, carbon efficiency, energy production is maximised or minimised.
- CCS and BECCS have been compared with Direct Air Capture. The forecasted cost of CO₂ capture for CCS and BECCS are in the order of 20-80 and 20-90 €/tCO₂, avoided although these costs are expected to fall significantly following demonstration. In contrast direct air capture (DAC) processes have high investment and high energy consumption. Resultant CO₂ capture costs are in the range 350 to 750 €/tCO₂, avoided. Demonstration may lead to a reduction to 100 €/tCO₂, avoided.
- Potential use of biomass in the European iron and steel industry has been assessed using a techno-economic model, to estimate the potential negative carbon emissions. The study also quantifies the risk related to the loss of competitive advantage against steel production in competing markets.
- Synthetic fuel production plants, based on a flexible sorption enhanced gasification (SEG) of biomass, has been investigated: one focused on Synthetic Natural Gas (SNG); and the other on dimethyl ether (DME) production.
- Pulp mills have the potential to achieve considerable negative net emissions of CO₂, because of their unique use of biomass. Partial capture will decrease the CO₂ capture cost considerably with the specific cost in the range of 41-57 €/t CO₂ captured. The production cost increases 3-19% depending primarily on the amount of CO₂ captured.

CO₂ UTILISATION

- CO₂ utilization could offer an important route for improving CO₂ management. Several different technical options and materials were explored including: concrete and carbonate based materials, commodity chemicals, durable carbon materials such as carbon composites or graphene.
- Other options included the use of CO₂, in combination with hydrogen produced from renewable energy sources, to make synthetic fuels such as methanol and even diesel substitutes.
- The economic viability of CO₂ sourced from steel, cement, pulp and paper, bioethanol and waste incineration to produce value-added chemicals, including methanol and urea formed part of this research area.

ENVIRONMENTAL IMPACTS

There were a number of studies related to potential leakage events. The US DOE National Risk Assessment Partnership (NRAP) has developed a number of models for this purpose:

- In one example geophysical and geochemical monitoring methods have been integrated to provide a diagnosis of leakage events.
- Pressure monitoring for early detection of large leaks could also be used to inform mitigation measures before such leaks become environmentally consequential but this depends on proximity to a suspect well.
- Other contributions evaluated the effectiveness of MT (magnetic telemetry) and Electrical Resistivity Tomography (ERT) to track CO₂ plumes.
- CO2CRC, Australia is undertaking a feasibility study for a planned CO₂ controlled release into a fault at a depth of ~30m and monitoring experiment on a shallow fault at the Otway Research Facility. Five properties including permeability were used to produce the final static model based on a 3D grid. The model has been developed to assist with the design of the experiment which will be conducted at the Otway site in early 2021.

WHAT WAS NEW IN AUSTRALIA?

- 1** The KHI led Hydrogen Energy Supply Chain Project in Victoria, Australia, aims to provide emission free hydrogen from Victorian Brown Coals to Japan. The project is in a pilot phase and does require large-scale storage options for CO₂ but will require a CCS solution for its commercial stage, via CarbonNet. The Gippsland Basin provides abundant storage opportunities and this could be the next large scale CCS project in Australia, following Chevron's Gorgon project.
- 2** The CO2CRC Otway project is progressing into its next major stage: testing high resolution, real time and non-invasive monitoring techniques, to reduce monitoring costs in commercial projects; and reduce the monitoring footprint for on- and offshore projects. The Final Investment Decision for the Otway Stage 3 project will be made in March 2019. International research organisations are invited to participate in subsurface research, together with CO2CRC, to fully capitalise on the existing infrastructure put in place by the end of 2019. Following the drilling and completion of a further four wells up to 1,700m depth, the CO2CRC Otway facility will have one CO₂ production well and seven monitoring and injection wells, all in hydraulic communication with each other. This will make the Otway facility the most instrumented subsurface infrastructure for CCS research.
- 3** The CTSCo project is being funded by ANLEC R&D and consists of a storage appraisal part, to develop a test injection of 200,000t of CO₂ at Glenhaven, Queensland to be followed by a full-scale capture at Millmerran coal power station with a larger storage injection into the same Precipice Formation at a location some hundreds of km further south.

DISCUSSION PANELS

Panel Discussion 1 – CO₂ Capture, Use and Storage (CCUS) in Developing Countries: Current Activities and Future Potential

This session had updates from donors and funding agencies such as the UK, Norway. Asian Development Bank (ADB) and the World Bank on funded project activities in developing countries.

Updates were given on the pilot CO₂-EOR in Indonesia, the new CCUS Centre in Mexico, and on the three centres of excellence supported by ADB in China: Shanghai; Guandong; and the National Centre at Yangchang Petroleum, noting that some smaller companies are getting interested in the CCUS market. Discussion highlighted that support from the World Bank, or other multilateral agencies such as the Asian Development Bank or the Green Climate Fund, is triggered by requests for funding from their client countries (developing countries) and/or direction from their donor countries. The session concluded that additional technical and financial support for developing countries is required for countries already working on CCS as well as countries who have yet to investigate their potential. In addition international collaboration and international knowledge exchange are key criteria for the future, as well as in-country political support.

Panel Discussion 2 – Unlocking CCUS Investment

This panel discussion covered the important topic of unlocking CCUS Investment. The panel, chaired by the IEA, included representatives from the US Department of Energy, Shell, Total and the World Bank.

the IEA's climate mitigation models show that CCS has a vital role in limiting CO₂ emissions by 2050 if the below 2°C target is to be met.

The IEA's climate mitigation models show that CCS has a vital role in limiting CO₂ emissions by 2050 if the below 2°C target is to be met. Regrettably of the 38 key industrial sectors that the IEA track only four are on track, 23 show some improvement and 11, including CCS, are off track. The US DOE drew attention to the importance of a combination of stable government policies, industry leadership, access to capital, and linked incentives, as well as viable technology. The Archer Daniels Midland Company (AMD) bioenergy project and the Petra Nova project in USA, jointly developed by NRG Energy and JX Nippon Oil, have already received significant support from the US Government, potentially boosted by the relative recent introduction of the enhanced 45Q tax credit for investment in industrial carbon mitigation.

Shell highlighted how the company's Sky Scenario Programme is moving it towards a low carbon future. Current investment in the Quest project, the Technology Centre Mongstad, Gorgon, Boundary Dam and Northern Lights demonstrates this commitment. Another key enterprise is the Oil and Gas Climate initiative. It is less than five years old and has already committed \$1B. About 120 CCS projects valued at \$120 B would be needed over 10 years, moreover this deployment rate could be achievable given the right incentives and commitment. World Bank engagement is already stimulating growing interest in CCS in nine developing economies including South Africa and Mexico.

The panel session concluded that more government commitment, as well as a legislative framework, is necessary. CCUS also needs champions to stress its importance in achieving global decarbonisation rather than a subsidy for the oil and coal industries.



Panel Discussion 3 – From Projects to Infinity; Large-Scale Project Experiences to be Shared

Organised by IEAGHG and the International Knowledge Centre, the panellists in this session discussed examples of how the experience gained from operational large-scale CCS could be shared. The panellists reflected on how this acquired knowledge could lead to the construction of more CCS plants. On the panel were International Knowledge Centre, JX Nippon, MHI and Shell representatives.

The ability to deliver the Quest CCS facility under budget and ahead of schedule were both accomplishments that inspire confidence and reflect positively on risk. Since 2014 Quest has successfully captured and safely stored 3 M tonnes CO₂. A key component of this success was Shell's stakeholder management programme, exemplified by its community outreach strategy. Government backing, knowledge sharing and experience gained from the project was incumbent on the company from the start.

JX Nippon stated that Petra Nova had also been delivered on schedule and on budget with 1 M tonnes of CO₂ captured in 2017. It was important to recognise that first-of-a-kind (FOAK) plants were, by nature, more expensive and that costs would be lower for successive plants. For example, FOAK plants generally required longer commissioning, have greater built-in redundancy and include a robust spare parts programme, particularly for long-lead items. Government support received for FOAK, and tax incentives, were vital to make a viable business case.

MHI focused mainly on the capture process at the Petra Nova plant, specifically MHI's KM CDR (Kansai Mitsubishi Carbon Dioxide Recovery) Process. This process with Kansai Electric's KS-1 solvent had been successfully deployed for many years prior to its use at Petra Nova. Initially at smaller commercial urea/fertiliser plants in the '90s further progress was achieved with its initial application on coal-fired power plant in the mid-2000s, followed by testing on a flue gas slipstream at Southern Company's Barry Power Station Plant in 2011. It took around 15 years for this technology to move from initial idea to successful fruition, plus all the investment required to move it along that track. Successfully negotiating that path has made Petra Nova, which captures 1.6Mtpa or 5,000tonnes/day of CO₂, the world's largest capture facility to date.

With Boundary Dam Unit 3 (BD3) the cost of modifying, upgrading and adding CO₂ capture to BD3 had been broadly equal to the cost of a new NGCC plant noting that the price of natural gas has dropped significantly since commissioning. Nonetheless, the BD3 plant has operated successfully and by March 2018, had captured around 2 Mtonnes of CO₂. The lessons learned at BD3 could lead to very substantial savings in both capital and operational costs with capture plant retrofitted to Sask Power's 300MW Shand Power Plant. The Shand CCS can integrate well with renewables, operate with a capture rate of up to 97%, lead to capital savings of 67% per tonne of CO₂ avoided, and all with no additional water requirement. With support and input from the International CCS Knowledge Centre, learnings from BD3 will not only aid the Shand project but will offer significant value to the broader CCS community.

The real benefits from international collaboration were highlighted. Close co-operation between the International CCS Knowledge Centre and China could stimulate development, reduce project costs and promote knowledge exchange. Global collaboration on climate change is a necessary precursor to drive the future opportunities that could see the technology flourish.

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Panel Discussion 4 – The Status and Potential of the Norwegian-EU CCS Project



This discussion panel aimed to provide an update of the CCS infrastructure in Norway and give an insight into how the country's work can ignite future CCS projects in the EU. It emphasised that there is a clear need for CCS and there is an urgency to develop business models and regulations to support its development.

Norcem-Brevik is a full-scale carbon capture plant on a cement works. It is technically feasible and could be operational by 2023 but this depends on economic support. The intention to install carbon capture on the Klemetsrud waste-to-energy plant outside Oslo was also described. It has an annual recycling capacity of 310,000 tons of waste and has the potential to capture 400,000 tons of CO₂ with 58% bio-CCS. An overview of the Northern Lights Project, and the scale-up potential for the storage aspect of the Norway full chain CCS project, emphasised that CO₂ storage is safe and highlighted the key importance of communication to stakeholders. Full design plans are set to be ready next year and several hydrogen initiatives are under evaluation. Total discussed their involvement in the Northern Lights project and summarised the importance of carbon compensation in the long-term and explained how the company wants to pave the way to carbon neutrality. Total see CCS as one of the ways they plan to provide clean energy to their customers. The panel reviewed the potential of CCS and how hydrogen can play an important role in a carbon emission-free energy supply. Contributors highlighted the significance of CCS which is now an integral part of company strategies such as Shell and Total. The panel emphasised that both the public and governments will need to come together to build a narrative on how CCS can contribute to meet the Paris Agreement.

Panel Discussion 5 – Putting the Value of CCS in Context

Cost can be the biggest reason given for the limited deployment of CCS. In this panel discussion, the panellists discussed how key metrics can be used to evaluate the potential success of CCS technologies. In contrast to the general perception, cost alone might not be the best metric to assess new systems and how they are implemented in the energy and industrial sectors.

The panel was composed of an interdisciplinary group with experience in power supply system modelling: MIT; Imperial College of London; NICE; EPRI and Lawrence Livermore National Laboratory. The electric generation mix across the US National Electrification Assessment (USNEA) scenarios were discussed. These modelled scenarios evaluate how rapid advances in innovative electric technologies can impact consumers' energy purchases and what implications they would have in terms of energy efficiency, the environment, and the electric grid. EPRI delivered the results of their research earlier in 2018, with the aim of discussing an optimum integration of new technologies within the electrical generation and supply system. One interesting observation that emerged from this study is that renewables, and other intermittent energies supplied to the grid, are pushing fossil-fuel facilities to operate in a way they are not designed for. As a consequence, the fossil fuel plant efficiency is lower, and the operational cost is higher. Energy storage using batteries could be a solution to avoid this forced flexibility. Fossil-fuel generation efficiencies would improve, the emissions would be reduced, and the operational lifetime of generation plant would increase. However, the cost of batteries can be high and additional research is still needed. In this energy mix, CCS can be more amenable to fossil fuel plants that operate at high capacity factors.

Following this presentation, the discussion was directed towards the advantages and disadvantages of cost metrics. While the CO₂ avoidance cost could be more explicit than the capture cost, the reference plant used to calculate these metrics can impact on the final result. The LCOE (levelized cost of electricity), regarded as a standard measure of electricity unit cost of generation, was considered to be a less reliable metric by the panel especially when integrated systems and variable demand on supply are considered. Complexities arise, for example, with balancing power demands. A possible solution could be implemented using three different timescales: instantaneous; daily; and seasonal. Another example of complexity is the addition of CCS to gas fired generation or the use of hydrogen from renewable sources to deliver low carbon electricity. These examples highlight the difficulty of using simple metrics to evaluate different options. A more detailed analysis of CCS using a full system analysis methodology is required.

The cost impact of CCS used in industrial processes was also raised. This parameter is measured by the increase in the cost per unit of product. However, changes to the production processes caused by retrofitting capture plant, or potential impacts on product specification, could present challenging conditions not necessarily reflected in the unit cost of product.

The most recent modelled integration of CCS with the energy mix in the electricity grid (systems analysis), can result in “super complicated” systems which fail to materialise and could lead to an overbuilt and under-utilised power system. If CCS is to be implemented the cost limitation has to be recognised. However, there is a strong likelihood that current site-specific estimates will lead to second generation cost reductions. Panellists commented that a different approach could be applied to the design of an electricity grid, for example based on targets or macroeconomic benefits. A more detailed analysis is needed and metrics like LCOE do not reflect the bigger picture.

In conclusion, the role of CCS is much more complicated than first envisioned 30 years ago. While simple metrics are quicker, settling the true value of CCS in energy and industrial systems will probably require a more complex analysis.

Panel Discussion 6 – Future Scenarios, how will CCS and Renewables Deliver 1.5?

This final panel session brought together five contributors who each outlined their view on how CCS combined with renewables, and other technologies, could meet the 1.5°C scenario by 2050.

One of the biggest challenges facing CCS is its high capital cost. In contrast there are renewables options with linked energy storage which would increase its supply cost. However, CCS could be compatible with renewable generated electricity without storage, and it is also the only realistic option for some industrial sectors.

One of the issues that faces CCS is its relatively recent public profile. Widespread publicity about the technology has only happened within the last decade and then mostly about its connection with power generation. Over the same time-frame there has been a dramatic increase in wind and solar deployment and a corresponding fall in the LCOE (and which often do not incorporate system costs) in these renewables.

Attention was drawn to the recent 1.5°C IPCC report which stressed that the route to emissions reduction lay in “combinations of new and existing technologies and practices, including electrification, hydrogen, sustainable bio-based feedstocks, product substitution, and carbon capture, utilization and storage (CCUS)”. Moreover emissions reductions by energy and process efficiency by themselves are insufficient for limiting warming to 1.5°C.

For the iron and steel industry there are clear limitations for alternatives to metallurgical coal. Hydrogen reduction is only at a pilot stage and will not be available in the immediate future. Alternative bio-based feedstocks would be resource constrained and steel is not a material that can be easily substituted by renewable alternatives such as wood. Consequently CCS is the only option for the large-scale decarbonisation of steel as well as industry in general.

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One of the reasons for the lack of CCS deployment is the underestimation at both national and international level of the technology's importance especially for the abatement of industrial emissions. The next bottle-neck is economic feasibility. The CO₂ avoidance cost using CCS in the European iron and steel sector (considering the cost of the full operating chain from capture, transport and storage) would be around 98 €/t CO₂. This would increase the cost of steel by 27% for an industry that is struggling. The dilemma for steel is how to reduce carbon emissions whilst remaining competitive.

One solution could be to de-risk investment and incentivise rather than penalise the industry thereby generating benefits down the value-stream including sustained employment. Learning from first-of-a-kind (FOAK) can lead to lower-cost second generation plant.

Two important questions were posed: what are the key bottlenecks for CCS and renewables to reach the 1.5° target; and what would need to be done in the next 5 to 10 years to get it on track? Attention was drawn to some major challenges previously mentioned in the opening plenary delivered by Laszlo Varro. In USA and Europe most coal-fired power plant is ~40 years old but, in contrast, in Asia most coal-fired plant is ~10 years old or less. So early phase-out in Asia is unrealistic. CCS is capital intensive and operation at low capacity factors is uneconomic. Moreover, if CCS is only used for industrial sources, it may not be economically viable to invest in the necessary transport and storage infrastructure to support it.

Other factors that have a negative influence on CCS include its lack of social acceptance in some world regions especially Europe. Climate change mitigation policies could be driven by ideological perspectives that are unfavourable to CCS rather than pragmatic approaches that CCS could fulfil. There could also be a lack of commitment due to a combination of economic decline coupled with increasing nationalism at a time of economically demanding policies.

There are some reasons for optimism. There are large CCS projects being commissioned in North America offering valuable industrial experience and favourable legislation leading to social acceptability. Some European countries notably Norway, Netherlands and the UK appear to be gearing-up for full-chain CCS deployment. An Australian-Japanese co-operative venture on clean hydrogen may open opportunities and examples for decarbonizing “difficult” sectors. Within the next 5 to 10 years further investment in full CCS chain projects on the scale of Northern Lights is needed. Finally CCS needs champions.

An optimistic view was provided from China emphasising the country's strong scientific research base backed by storage demonstration. Capture and storage within the country has been estimated to be 30 Mtonnes/year. The National CCS Roadmap for China was issued in December following COP21, in Paris. In 2016 nine projects received more than 100 million yuan (US\$14.4 M, 12.6 M €) funding per year.

STUDENT RECEPTION

A Student reception was organised to bring student attendees together to network between themselves and with a number of selected experts in a relaxed and friendly atmosphere. The GHGT conference organisers recognise the essential role students play in the future development of greenhouse gas mitigation technologies. Not only are they conducting essential research but they will also form the future skilled workforce and decision makers.

With sponsorship from INPEX, the student reception attracted over 100 students including many IEAGHG Summer School Alumni who were able to catch up and discuss their progress. The International CCS Knowledge Centre in Regina, Saskatchewan, Canada also announced their plan to host IEAGHG's 2019 Summer School. Presentations at the reception reinforced the role that the students will play in the development of CCS and encouraged them to take advantage of the networking opportunities provided by this conference.

Feedback was sought from students in response to two questions. "What would you like to tell the world and the conference?" It prompted the following responses:

- CCS will be key in a sustainable future with a range of energy sources
- CCS needs better marketing and big companies supporting the cause
- More demonstration projects are needed in developing countries
- Climate change is a political, social and economic problem. A political change in direction is needed more than scientific effort.
- CCS needs scientists to be good on the podium as well as in the lab. More time should be spent with policy makers and economists.

And in response to "How can we better communicate the value of CCS?"

- Public communication is key – explaining the significance of CCS is part of a solution but not the only solution
- Emphasise hydrogen production
- Emphasise the urgency and value of CCU
- Capacity building programmes should be established
- CCS education in schools. Ruta Karolyte from Edinburgh University has created a CO₂ game aimed at reaching a demographic outside the CCS community – why not use it in schools and elsewhere
- Sell CCS as a product and help to change the current narrative. CCS needs to be sold as a necessity not as an option.
- Listen and respond to issues raised and couple this approach to transparent decision making.







*Mike Monea, President/CEO
of the International CCS
Knowledge Centre*



CLOSING PANEL

> GHGT-14 CLOSING PANEL “A NEW NARRATIVE”

GHGT-14 was brought to a close on Thursday 26th October with a final panel to discuss ‘The CCS Narrative’. The panel consisted of: the chair Gabrielle Walker – Xynteo; Bill Spence – representing OGCI; Fiona Wild – BHP; Keith Whiriskey – Bellona; Tony Wood – Grattan Institute.

> OPENING: THE CCS NARRATIVE

The session proposed a need for a more consistent, powerful narrative for CCS. There is a current OGCI initiative, along with BHP and Total, with the objective of creating some positive energy to reinvigorate the narrative around CCS. The need to reach wider audiences to broadcast the positive CCS message was stressed. The current communication barriers also need to be reviewed and how they can be overcome.

In the panel’s view the CCS narrative is not a promotional campaign but rather a means to express the current world view. The narrative is a reflection by the CCS community on why it is implemented. Unfortunately, the narrative is currently not giving the right impression with the general public and it is changing rapidly.

The idea of ‘fatigue’ within the CCS community, with project cancellations and lack of policy support, was discussed and how to keep the momentum for CCS extending well into the future. In the world of politics and policy initiatives technology facts and numbers are available but information is not enough. CCS needs strong global communicators to boost its image.

> LISTENING IS KEY TO UNDERSTANDING HOW TO TALK TO YOUR AUDIENCE

As a CCS community we need to listen more rather than focussing on what to say next. A constructive approach was proposed - listen, understand your audience, and then develop a more relevant message. Thinking about who the right person is to communicate with the audience is also important as well as understanding where peoples’ points of views come from.

Understanding your audience’s perspective allows engagement with them and the opportunity to educate them and decouple their concerns in relation to CCS.

> THE VALUE VS THE COST OF CCS

The language used for policy makers and politicians is influential. The benefits of CCS needs to be articulated effectively especially the costs associated with the technology. This issue is one of the more regularly discussed ‘barriers’ particularly by comparison with established renewable energy technologies like solar and wind which are now highly competitive technologies but were initially very expensive. This technological evolution is consequently beneficial to political agendas.

One of the panellists expressed the view that although cost is a real issue, RD&D is currently addressing this challenge. Cost is not what’s stopping people getting on board, it’s used as an excuse. The comparison with renewables is also an over simplified narrative that has a negative impact on the CCS message especially with the public who are apt to think the problem can be easily solved.



> LOW CARBON PRODUCTS

It has been argued that the lack of beneficial ‘product’ associated with storing CO₂ makes CCS non-tangible. The panel proposed that low carbon steel and cement with associated CCS could be a means of demonstrating the benefits of CCS more effectively.

The CCS community needs to move the discussion from science to outcome. For example, low carbon products used for new road and tunnel developments is likely to get public support. Big companies will start to ask for these products and a competitive market will emerge.

> THERE IS A LACK OF TRUST

Another key element to the current CCS narrative is a lack of trust between the main-stream audience and technical experts currently conveying the message. The public don’t trust the oil, gas and coal industries. They also distrust government commitment to CCS investment when funding pledges and competitions are cancelled. One sentiment regularly expressed surrounds ‘trust’. It is often assumed that a company has an agenda. What is required is a combination of different views with different reasons for wanting CCS. “Unlikely alliances”, such as unions, companies and NGOs, need to get the message across. Human nature is sceptical and often, what is required, is an independent audit that should be provided more willingly. In conflict it’s normal to want a second opinion. CCS needs to be verified outside the connected industry.

Trust can be gained by actually doing and observing projects but that can’t happen unless there are live projects underway.

> CCS AMBASSADORS

The panel ended with a discussion on who should be an ambassador.

Investors should be the focus. If this community started to think about catalytic investment in CCS it could have a really powerful impact.

Champions are going to be people that will be worse off without CCS. Those people may not be aware of CCS yet finding a solution to emission abatement should be their biggest motivator.

It was suggested that companies that don't become carbon neutral in 50 years will be at financial risk. The profile of the CCS narrative needs to be raised in the Treasury and those influential to the Exchequer or equivalent. He stressed that it's not just about the technical message, "facts don't change feelings", but who's saying it, how are they saying it and who are they saying it to.



The CCS Ambassadors at the Closing Session of GHGT-14

GREENMAN AWARD

To acknowledge their significant contributions to CCS the Greenman Award was given by Professor Kelly Thambimuthu FTSE (Chair of IEAGHG Executive Committee and a Co-chair of the conference) to two exceptional people: Susan Hovorka, a senior research scientist at The University of Texas at Austin; and John Gale, General Manager of IEAGHG. The Greenman Award is seen as the 'Nobel Prize' of CCS.

Susan Hovorka received the Greenman Award for her significant contributions to the development of greenhouse gas control technologies. Sue is the principal investigator and founder of the Gulf Coast Carbon Center within the Bureau of Economic Geology at The University of Texas at Austin, Jackson School of Geosciences, and responsible for developing and monitoring large-scale CO₂ storage projects.

In response to this award Sue said "I am honoured to receive this award in recognition of my team's work. Joining the ranks of the prestigious individuals who have won this in the past illustrates the overall success of our work in greenhouse gas mitigation."

The second Greenman Award was presented to John Gale, General Manager of IEAGHG. John's foray into CCS began about 19 years ago. He has had a very significant role in the creation, development and supervision of the IEAGHG Weyburn-Midale CO₂-EOR Monitoring and Storage project. He also led the drafting of a chapter in the 2005 IPCC Special Report on CO₂ Capture and Storage. He was the founding editor in chief of the International Journal of Greenhouse Gas Control and managed it's growth for a decade in establishing it as the foremost scientific publication for CCS. In 2007 John became the General Manager of the IEAGHG and has overseen delivery of a very robust technical programme that has consolidated IEAGHG as a global centre of excellence in CCS

Only 12 people have received the Greenman Award since its inception in 1996, including this year's winners. An ancient symbol found in many cultures throughout the world, the Greenman represents the union of humans and the natural world.



The GHGT conference series has a tradition of presenting an award to an individual whose vital contribution towards progressing CCS technologies, and enhancing our understanding of the process of mitigating greenhouse gas emissions, is recognised.

Recipients of this prestigious award dated until 2018:

Meyer Steinberg; 1996
Wim Turkenburg; 1996
Yoichi Kaya; 1996
Olav Kårstad; 2006
William D. Gunter; 2008
Howard Herzog; 2010
Peter Cook; 2010
Sally Benson; 2012
Hallvard Svendsen; 2014
Julio Friedmann; 2016
Susan Havorka; 2018
John Gale; 2018

**ghgt-14**

IEA GREENHOUSE GAS R&D PROGRAMME

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Gunter Siddiqi
Gunter Siddiqi
IEAGHG Executive
Committee Vice Chair

Åse Slagtern
Åse Slagtern
IEAGHG Executive
Committee Vice Chair

K.V. Thambimuthu
Kelly Thambimuthu
IEAGHG Executive
Committee Chair

PRESENTED TO

*In Recognition of Contributions Made to the
Development of Greenhouse Gas
Control Technologies*

The Greenman Award is given to an individual in recognition of a significant contribution to the development of the GHGT conference series, or for services to the development of knowledge and understanding of the issues involved with CCS and Greenhouse Gas Control Technologies.

Though no-one knows for sure the real meaning of the Greenman, everyone who sees him understands that he stands for something very profound. He represents the union of the human and the green world and shows us a possible way forward in helping to put right some of the damage caused.

POST-EVENT SITE TOURS

122 people took the opportunity to view CO2CRC's internationally-renowned Otway Research Facility post-GHGT-14. The visits took place on Friday 26th and Saturday 27th October at the site located in Nirranda South, Victoria, Australia. CO2CRC's carbon dioxide storage and capture experts showed the visitors around the research facility. The tours provided delegates with an opportunity to experience an internationally renowned research facility which many had read about in scientific journals or heard about at conferences. The groups also enjoyed a gourmet Aussie barbeque lunch cooked by volunteers from the local primary school.



PRESS EVENTS

During the conference two notable events drew attention from the media. The signing of a collaboration agreement between Professor Kelly Thambimuthu, on behalf of the IEA Greenhouse Gas R&D Programme (IEAGHG), and Mike Monea, President and CEO of the International CCS Knowledge Centre. The aim of the agreement is to combine the promotion and acceleration of large-scale carbon capture and storage. This combined effort will provide peer review of publications and ensure that accurate, relevant and current knowledge about CCS is freely available.



Kelly commented that “CCS enables very deep reductions in CO₂ emissions from the use of existing and new fossil fuel based energy infrastructure. Additionally, its deployment with sustainably harvested and renewable bioenergy resources enables deep reductions of CO₂ directly from the atmosphere. Both are critical to a climate change mitigation strategy to limit global warming to 1.5 °C.”

After the signing Mike Monea observed “We are excited by this alliance with IEAGHG. It takes many working towards a common goal. Globally we need a definitive shift in effort on climate change action. CCS is needed now as a means for countries and their citizens to manage current and future GHG emissions.”

The second media event was a book signing by the notable MIT Senior Research Engineer, Howard J Herzog who endorsed a limited number of his 2018 book “Carbon Capture”. Howard Herzog’s achievements include the 2010 Greenman Award in recognition of his considerable contribution to the development of CCS which also includes his role as a co-ordinating lead author for the IPCC Special Assessment Report on CCS, published in 2005.



THE NEXT GHGT

Mr. Mohammad Abu-Zahra from Khalifa University, invited the audience to visit the vibrant and very modern United Arab Emirates (UAE) in 2020 for GHGT-15. It will be the first time that a GHGT conference has been held in the Middle East. The newly-established Khalifa University of Science and Technology (KU) combines the Masdar Institute of Science and Technology (MI), the Khalifa University of Science, Technology and Research (KUSTAR) and the Petroleum Institute (PI) into one world-class, research-intensive institution. The university is a key part of Abu Dhabi's and the UAE's rapidly developing knowledge economy. The country also hosts the World's first carbon capture from a steel plant. The Emirates Steel Industries plant now captures around 0.8 million tonnes of CO₂ per year which is supplied to ADNOC's onshore Al Rumaitha and Bab fields for enhanced oil recovery via a 43 km (27 miles) pipeline.

Abu Dhabi is a thoroughly modern destination with world class hotels, shopping malls and other tourist attractions. Its many fine buildings including the Sheikh Zayed Grand Mosque. The more adventurous have the opportunity to explore the less well known side of the UAE including the magnificent desert dunes on the edge of the Empty Quarter and awe-inspiring wadis in the north-east bordering Oman.



GHGT-14 is hosted by:



Australian Government
Department of Industry,
Innovation and Science



The 12 Apostles – an impressive limestone formation located three hours from Melbourne

Custodian of the conference series:

