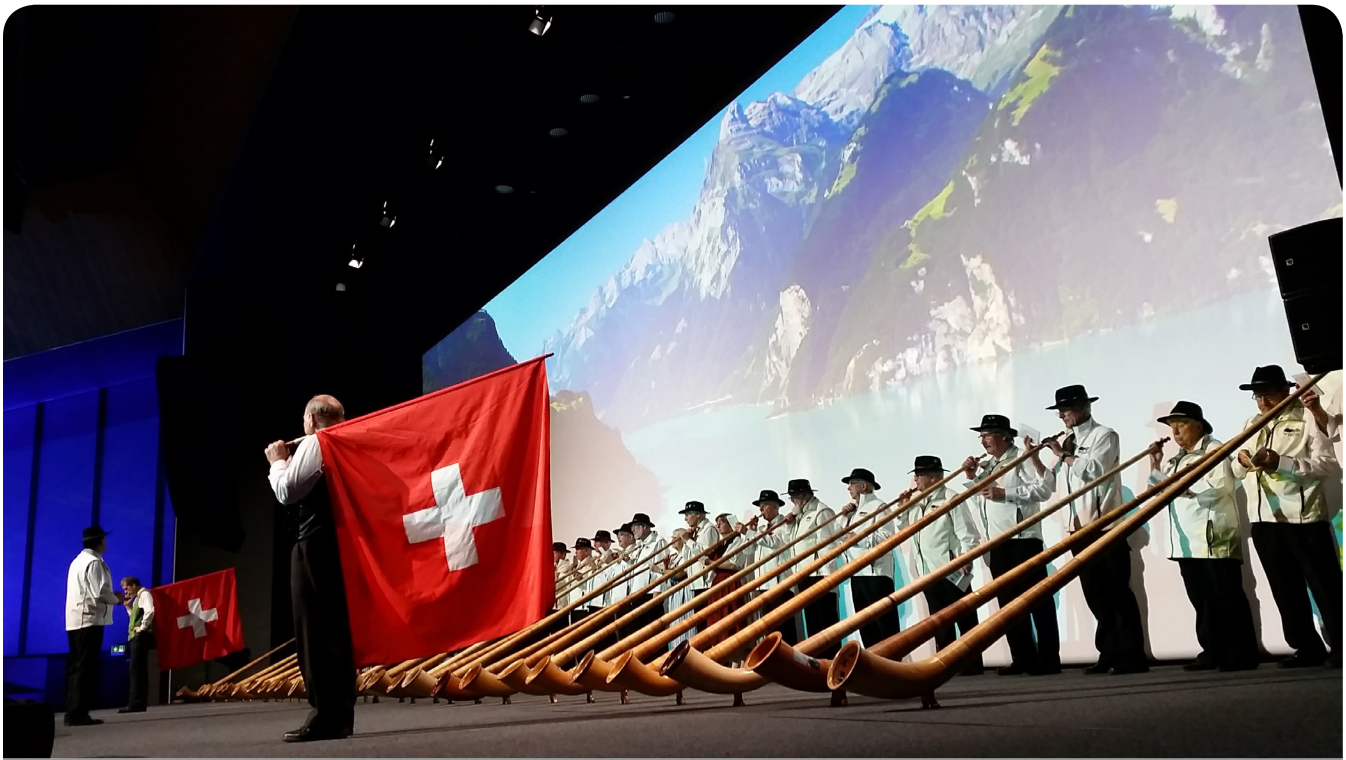
ghgt-13

Conference Summary

13th International Conference on
Greenhouse Gas Control Technologies

November 14th - 18th, 2016
SwissTech Convention Center - Lausanne, Switzerland



Académie Suisse de Cor des Alpes, performers at the GHGT-13 conference dinner on Thursday 17th November

Contents

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IEAGHG would like to thank all those who worked on this publication.

GHGT-13 Background

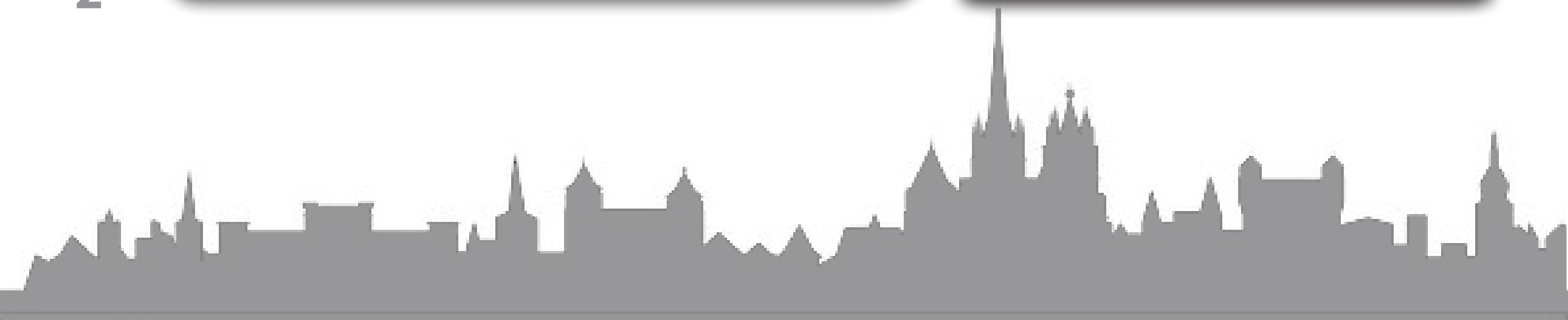
The 13th conference in the GHGT series was held in Lausanne, Switzerland in November 2016. The hosts for the event were the world renowned Swiss Research Institute the Ecole Polytechnique Fédérale de Lausanne (EPFL), supported by the Federal Government of Switzerland and its Swiss Federal Office of Energy (SFOE). The event was held at the newly constructed Swiss Tech Convention Centre. The convention centre is a showcase for 'Clean Tech' incorporating geothermal supporting pillars heating and cooling; photovoltaic panels to produce electricity and prevent the inside of the centre from overheating, all of which reduces the greenhouse gas footprint of the centre which fully aligns with the conference aims.

Of course the GHGT conferences focus on presenting the cutting edge research on one low carbon technology option, Carbon Dioxide Capture and Storage (CCS). Switzerland has active research programmes on CCS one of which is at EPFL, which is interesting in a country more known for its reliance on nuclear power and interest in geothermal energy. However, the Paul Scherrer Institute (PSI) has suggested Switzerland will need to deploy CCS on natural gas to implement Switzerland's Energy Strategy 2050 at least-cost investments whilst achieving greenhouse gas reduction targets. Hence the Swiss interest in hosting the GHGT conference.

The story of GHGT-13 from Twitter, courtesy of UKCCSRC at https://storify.com/ukccsrc/ghgt-13

The SwissTech Convention Center is a conference centre sited on the École polytechnique fédérale de Lausanne (EPFL), Switzerland. The Center was the location for the GHGT-13 conference.

"CCS is a fact, it works, it's safe and is moving from the energy sector into other sectors of economic activity", Gunter Siddiqi, SFOE & co-chair of the GHGT-13 Steering Committee



GHGT-13 Backdrop

MARRAKECH COP22|CMP12
UN CLIMATE CHANGE CONFERENCE 2016

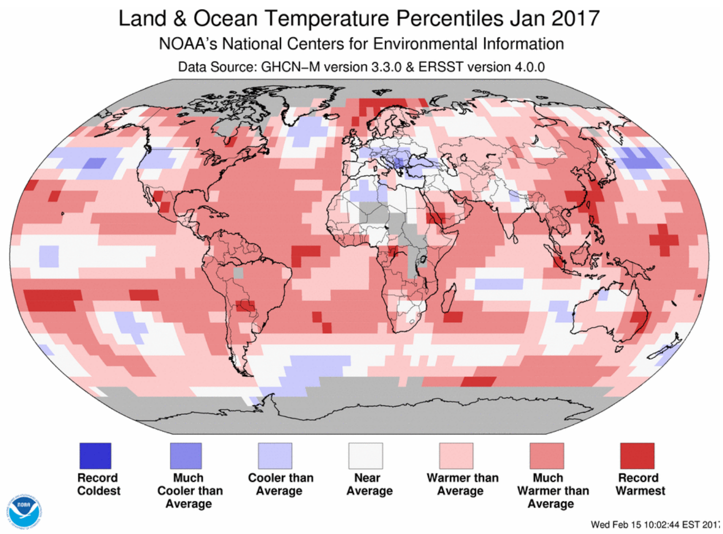
The GHGT-13 conference comes one year after the Paris Agreement, which set a new global ambition to limit temperature rise to below 2⁰C. The IPCC 5th Assessment report that came out in 2014 demonstrated that CCS is a key mitigation technology that needs to be deployed if we are going to meet the pre-Paris ambition of limiting temperature rise to 2⁰C. Going to below 2⁰C infers that CCS will be an even more relevant as a mitigation technology. The research and status reports on CCS at the GHGT-13 conference therefore took on more relevance, and help to strongly underpin the message that CCS is ready for global deployment.

At the same time as the GHGT-13 we had the COP22 underway in Marrakech. This was an important event and was the first opportunity for the countries to gather and begin the thought process of ramping up their greenhouse gas mitigation ambitions to meet the new challenge set by the Paris Agreement. With people moving between GHGT-13 and COP22 the messaging was clear, CCS is ready to be part of your countries solution to achieving the below 2⁰C ambition you signed up to in Paris and which countries ratified under a year later.

Laurence Tubiana, COP 21/CMP 11 Presidency; UNFCCC Executive Secretary Christiana Figueres; UN Secretary-General Ban Ki-moon; COP 21/CMP 11 President Laurent Fabius, Foreign Minister, France; and President François Hollande, France, celebrate the adoption of the Paris Agreement: Photo by IISD/Kiara Worth (www.iisd.ca/climate/cop21/enb/images/12dec/3K1A5493.jpg)

GHGT-13 Statistics

Setting the Scene – Key Points from Plenary Sessions



January 2017 Temperature Percentiles Map

Professor Thomas Stocker from the University of Bern presented the hard facts on climate change as a opener to the event and a grounding for all attendees as to why they were here and what their research is aimed to overcome. He reminded the audience that the concentrations of CO_2 have now increased to levels unprecedented in at least the last 800,000 years. As a consequence, global average surface temperatures are the highest ever and artic sea ice cover is now at its lowest ever.

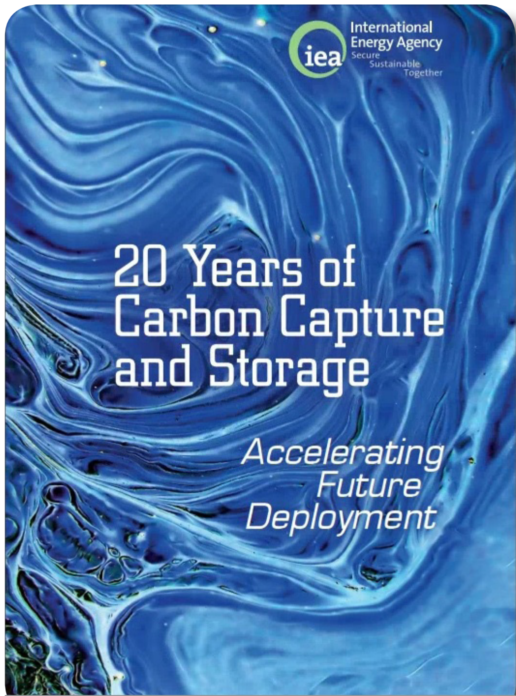
The IPCC's 5^{th} Assessment report was clear in its key messages:

- Warming of the climate system is unequivocal.
- Human influence on the climate system is clear.
- Continued GHG emissions will cause further warming.
- Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.

Reflecting on the Paris Agreement Prof Stocker reminded the audience that any climate target implies a limited carbon budget. At current emission rates the CO_2 budget will be exhausted by about 2035 and hence the 2°C target will be lost.

This was a strong message advocating the need for urgent significant mitigation action by countries.

A new report[1] from the International Energy Agency (IEA) was launched at GHGT-13, by ***Kamel Ben Naceur***, "20 years of CCS, Accelerating Future Deployment". The report reflects on two decades of progress and deployment of CCS, recognising the CCS deployment has not been as rapid as we all would have liked mainly as a result of fluctuating policy support. The IEA report however takes up the gauntlet thrown down by Thomas Stocker and highlights what needs to be done to accelerate CCS deployment in the coming years.



"Deployment of CCS will not be optional in implementing the Paris Agreement" Dr Fatih Birol, Executive Director, IEA

Learning from the past, first and foremost, stable policies, including financial support, are urgently needed to allow CCS deployment to accelerate in the coming decades.

In addition, the IEA feel that new approaches and a re-focusing of efforts can also promote faster deployment. New approaches identified by the IEA in its research work include:

- Greater emphasis on CCS retrofitting, particularly in countries like China
- Cultivating early opportunities for BioCCS and breaking down barriers to deployment
- Developing markets for "clean products"
- Moving from conventional enhanced oil recovery (EOR) practices to "EOR+" for verifiable CO_2 storage
- Disaggregating the CCS value chain to enable new business models to emerge

[1]A copy of the report is available to download from:
www.iea.org/publications/freepublications/publication/20-years-of-carbon-capture-and-storage.html

Trude Sundset, Gassnova CEO updated the attendees on CCS developments in Norway. Norway of course being the country that leads the deployment of CCS in Europe with demonstration projects like Sleipner and Snohvit and the Capture Test Centre Mongstad. Trude shared Norway's new plans for CCS. Reducing emissions from industrial sources is at the heart of Norway's plans to be carbon neutral by 2030. Gassnova is now undertaking three FEED studies for CCS application on a cement works, a waste incinerator and an ammonia fertiliser plant. Separately Statoil is looking at the feasibility of a shuttle ship based transport system with offshore storage in a deep saline formation. In this scheme the capture and transport/storage activities will be separated with a storage company managing the transport/storage network. Plans are to have at least one CCS project operating at an industrial facility by 2022. Whichever one is chosen it will be the first demonstration of CCS at such an industrial facility.

"CCS - the time is now", Trude Sundset, Gassnova CEO

The Norwegian plans separate capture at the industrial facilities with a separate company managing the transport and storage element. This is in line with the IEA's earlier comment on the need to disaggregate the CCS value chain.

CCS Deployment

The conference provided the GHGT-13 attendees with updates on the status of a number of the CCS demonstration projects that were underway at the time of the conference. The projects included: Sleipner, Boundary Dam 3, Quest, Kemper County, Tomakomai and a CCU demonstration project operating in Saudi Arabia, Jubail Industrial City. Some of the key points taken from the projects include:

- **The Boundary Dam 3 and Quest Projects (both in Canada) had been operating for over one year and both had captured 1Mt CO_2 at the time of the conference.**
- **The Boundary Dam 3 and Quest projects use different commercially available Cansolv capture technology**
- **The Boundary Dam 3 project was the world's first commercial scale application of post combustion capture technology on a coal fired power plant**
- **The Sleipner project in the North Sea, the world's first commercial demonstration of CCS technology has now been capturing and injecting CO_2 continuously for 20 years with 16Mt CO_2 successfully stored and monitored to date.**
- **The Boundary Dam 3 and Quest projects had strong government support which was essential to get these projects operational.**
- **The Kemper County project, when operational, will be the world's first commercial demonstration of pre combustion capture. The Selexol capture unit at Kemper County was built at cost and without any time delays. Non capture system technical issues have caused the delays and cost over runs.**
- **The Boundary Dam 3 and Kemper Projects both use local coal which has predictable long term prices. In both cases gas prices were considered to be too variable to consider building a gas fired power plant instead.**
- **The Boundary Dam 3 and Kemper Projects business models are based on sale of electricity and products (CO_2 for EOR, ash & sulphur)**
- **At Boundary Dam 3 and Quest different approaches to construction were used at the two sites.**
    - **At Quest the capture equipment was built off site in modules, shipped and assembled on site.**
    - **At Boundary Dam 3 the CO_2 and SO_2 scrubbers were assembled on site.**

- **The Tomakomai and Quest projects both capture CO_2 from hydrogen production units at refineries.**
  - **Both projects capture the gas after the methane reformer and use amine based post combustion capture technology to capture the CO_2.**
  - **Quest uses the Cansolv ADIP-X system on the full process flow and captures, whereas Tomakomai uses a 2 stage scrubbing process using a BASF solvent on a slip stream only (100/000t/y).**

- **The Quest, Sleipner and Tomakomai projects are injecting into saline aquifers (onshore and offshore).**
  - **Quest transports the captured CO_2 65km by pipeline and injects it onshore into a porous sandstone 2km underground**
  - **Tomakomai injects the CO_2 onshore into a 3km deviated well to inject it into a porous sandstone 1.2km under the sea bed.**
  - **Sleipner has provided great experience in seismic monitoring of the CO_2 plume. Tomakomai is having to develop and apply marine environmental monitoring. Quest is showing how to reduce monitoring costs for larger-scale projects.**

- **The Jubail Industrial City, CCUS project uses the captured CO_2 to produce methanol and urea.**
  - **The project is the first commercial application of Linde post combustion capture technology and world's first capture unit on an ethylene glycol plant.**
  - **Capturing 500, 000Mt CO_2 pa it is the biggest commercial capture unit until the MHI unit at the NRG Parish CCs demonstration project came on stream in 2017.**

- **The Quest, Kemper, Boundary Dam and Tomakomai projects are all aware of the need for stakeholder engagement and all have active public communication/engagement programmes.**
  - **At Tomakomai monitoring data is broadcast live in the town hall for public viewing**

Applied Research on CCS has been underway for Two Decades

To emphasise the message that applied research on CCS has been underway for two decades, the Carbon Capture Project (CCP), a joint industry project formed by oil companies presented the results of 16 years of collaborative research on CCS deployment. The CCP project has been undertaken under 4 phases and contains work areas on; capture, storage policy and regulation and also has a strong communication/outreach component. One of the benefits of such a collaborative arrangement enabled them to leverage their resources and gain access to industrial facilities. Some of the many successes of the CCP were:

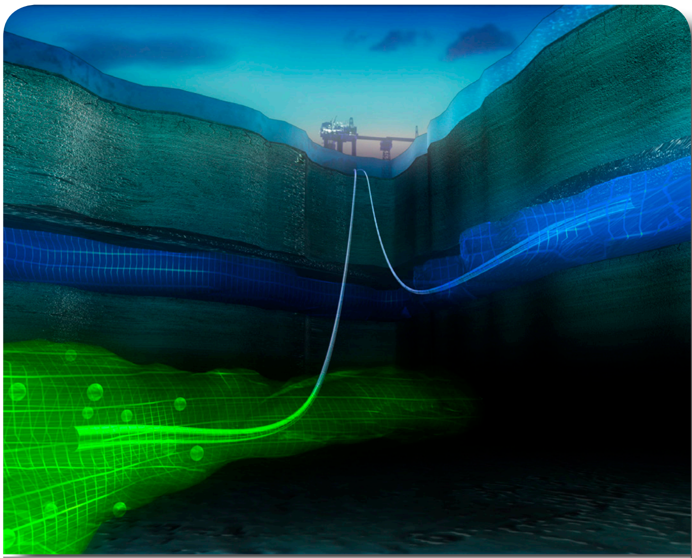
On Capture: Demonstrations of the principle of oxy-fired FCC, oxy-fired once through steam generators (OTSG) for use in refinery and heavy oil upgrading operations that reduce the cost of capture by producing high concentration CO_2 streams instead of more dilute ones.

On Storage: Strengthened the science of storage with a focus on well integrity,

On Policy and Regulation: A report was published in 2016 on Best Practice for Transitioning from CO_2-EOR to CO_2 Storage

In a nice synergy with the conference CCP phase 4 is undertaking well-sealing experiment, at the Mont Terri Rock Laboratory at St-Ursanne in the canton of Jura north of Lausanne.

Mont Terri Underground Laboratory. Image courtesy of Mont Terri Project.



Sleipner. Illustration: Statoil. Photo courtesy of Gemini, Research news from NTNU & SINTEF (http://geminiresearchnews.com/viewpoints/norway-should-store-europes-co2/)

Of course the longest operating CCS demonstration project is the Sleipner project in the North Sea which has been injecting CO_2 continuously since 1996. The 20th anniversary of this project was marked by the IEA book and also a discussion panel at GHGT. The discussion panel considered how best to transfer knowledge globally from Sleipner. In considering how to further improve transferring knowledge globally from Sleipner, the discussion panel heard about the global offshore storage potential, and a considerable exercise on storage assessments by geological organisations in East and South East Asia in the CCOP CCS-M initiative, as well as the new interest from Nigeria. The value of being able to re-use existing oil and gas infrastructure, as with Sleipner, was emphasised. The discussion concluded resoundingly that Sleipner was extremely relevant globally, and to encourage further knowledge sharing through data sharing, papers and workshops, involving developing countries and relevant funding agencies especially.

The monitoring programme at Sleipner has been a show case for demonstrating both conformance and containment. Repeated seismic and gravimetric surveys have been conducted throughout the lifetime of the project. Statoil and partners have shared seismic data (via IEAGHG) for others to use in modelling.

Research Achievements – Key Highlights

With over 800 presentations in both oral and poster sessions at the conference it is always difficult to provide a composite review of highlights from the conference. Overall, the Technical Programme Committee (TPC) felt that the quality of the papers at GHGT-13 was very good.

Some highlights (by no means an exhaustive list) identified by the TPC and IEAGHG are summarised here:

The International Test Centre Network and testing facilities like the National Carbon Capture Centre (above) and Technology Centre Mongstad are playing a crucial role in scaling up and de-risking new capture technology options (Photo courtesy of www.nationalcarboncapturecenter.com).

On Post Combustion Capture *considerable progress since the last conference was noted. In particular:*

- Several second and third generation amine scrubbing technologies have advanced successfully to the testing at the 1 and 10MW scales.
- Process modelling of amine scrubbing continues to produce improvements in solvents and process configurations.
- Third generation alternative solvents promise to further improve energy and cost performance of amine systems.
- Modelling and measurements of amine aerosols have developed understanding and methods to address this problem.

- New investigators of corrosion in amine scrubbing had identified ferrous carbonate as an effective protective layer for use of carbon steel in amine scrubbing.
- Continuing work on novel systems is adding to the catalogue of acceptable and unacceptable solvents.

On CCS for Industrial Sources:

- A considerable number of papers were presented that focused on CO_2 capture from the cement industry.
- Oxyfuel combustion technology offers good potential to reduce the costs of CO_2 capture in a kiln or pre-calciner used by the cement industry.
- Techno economic studies on industry CCS are now being reported. However, to better understand the potential for CCS in industry more studies are needed and the cost and technical data need to be transparent to allow cost comparisons to be made.

On Geologic storage of CO_2:

- The benefits of 20 years of experience and investment in CO_2 storage is paying huge dividends in the advancement of knowledge and capacity to implement CCS at scale.
- Significant advances in the understanding and quantification of CO_2 trapping mechanisms, including residual gas trapping, capillary trapping, and mineral trapping, and at pore, core, and intermediate scales have been observed.
- Also there have been significant advances in the development of detailed and complex models of the subsurface geology and modelling of CO_2 fate and transport on time scales of hundreds of years. Some additional synergistic aspects were represented by a number of papers integrating modelling, monitoring and risk assessments, from the work of the National Risk Assessment Program NRAP.
- Very high quality modelling and experimental scientific work in geomechanics were shown in the conference. Attention has been paid particularly to the geomechanical response of the cap rock in order to ensure its integrity during CO_2 injection; possible healing mechanisms and maximum overpressure generation were carefully investigated in order to prevent possible CO_2 leakages, making CCS a more reliable and secure technology.
- Modelling of complex multi-physical mechanisms involving thermo-chemo-hydro-mechanical processes during the CO_2 storage underwent significant advances in its development, allowing reliable both short and long term predictions and risk management of the reservoir were also presented. Advances were seen in quality ranking assessment system of the CO_2 storage sites with the experience of Norway, including criteria on reservoir properties, seal properties, storage safety, data coverage and most importantly the knowledge gaps in terms of available geological data and models.

On Storage Monitoring:

- The CCS community is benefiting from comparison of techniques and vendors of equipment at large-scale projects (Aquistore and Quest) from which other projects can learn.
- New marine environmental monitoring approaches are being applied at Tomakomai, taking concepts developed onshore and developing these for offshore.
- In general, for both onshore and offshore, there is increasing awareness of the complexities of using environmental baselines alone for leakage detection, including the influence on these from climate change and the risks of false positives.

On CO_2-EOR:

- Really good advances are being made in the area of CO_2-EOR for storage.
- Good work out of Europe better quantifies the supply curves for CO_2-EOR and make the prospects look less daunting than in the past.
- There is a growing consensus that it is possible to deliver emissions reductions from CCS+CO_2-EOR; however, more work is needed to go from carbon-accounting to true life-cycle assessment.

On CO_2 Transport:

- Transport remains a key prerequisite to implement CCS particularly for industry.
- Transport infrastructure may need governance by the government and (international) public or public/private investment will be required to develop an adequate infrastructure.
- There is renewed interest in ship transport of CO_2.
- CO_2 pipelines typically compete with ship transport over smaller distances and higher volumes, but contracts over sufficient years are needed to reduce investment risks.

On Negative Emissions:

- Given the increasing awareness of the need for negative emission technologies, there was identification on the potential for Bio-CCS applications and its benefits in waste to energy, land-fill gas, and the pulp and paper industry, as well as in the power sector.
- Policies that credits negative emissions are needed to realise the mitigation benefits of this technology emissions
- Potential for negative emissions via CCS can be enhanced by improved conversion technology (e.g. CLC).

On CO_2 Utilisation:

- CO_2 mineralisation represents the next utilisation option after CO_2-EOR that offers permanent storage of CO_2. Further work is needed on the overall energy needs and environmental impacts of this option.

Discussion Panels – CO_2 Utilisation, Negative Emissions, other Discussion Sessions

A discussion panel on the role of CO_2 utilisation and conversion proved to be extremely well attended, and highly emotive. Some of the main conclusions drawn were:

Niall Mac Dowell, Clean Fossil and Bioenergy Research Group, Imperial College (Image courtesy of Kristin Jordal - pic.twitter.com/Zuv97NAcAx)

- **CO_2 utilisation and conversion to chemicals is a new topic, with many Governments funding research programmes now in this area**
- **There was a consensus that to meet the below 2°C target set at COP22 we need mitigation options that permanently remove CO_2 from the atmosphere**
- **CO_2-EOR is the leading form of CO_2 utilisation and has the potential to store permanently some CO_2**
- **Manufacturing chemical products like methanol and urea do not permanently store CO_2 and therefore are not mitigation options.**
- **Utilising CO_2 to make products like methanol and urea could help with the installation of capture plants on new industry processes, like SABIC's capture plant on its polyethylene process in Saudi Arabia.**
- **Utilising CO_2 from chemical industry is not likely to help develop a transport infrastructure that could take significant volumes of CO_2 to offshore storage sites in Europe.**
- **Expecting large amounts of free renewable energy to be available to convert industrial CO_2 to chemicals is improbable.**
- **Some CO_2 based polymers could conceivably last for 50-100 years but that is still not long enough to count as a mitigation option.**
- **Mineralisation is a niche opportunity not a global solution and is at very best CO_2 neutral as it only serves to recombine minerals that have been de-carbonated with the CO_2 they lost during processing.**

There was an absorbing session on "Large-Capture Pilots" Several speakers provided the audience with the benefit of their extensive practical experience of managing or operating capture pilots at the 10+ MWe scale at test facilities like Test Centre Mongstad. They described how testing often progressed through two or three stages, sometimes more, to move from testing at, say, the 0.1 MWe scale to demonstration. It was recognised that this was an exceedingly expensive way to de-risk new capture technologies sufficiently to gain the confidence necessary to design and operate a utility-sized capture plant. This approach could take 10+years to bring a new capture technology to the market place.

CCSI

Carbon Capture Simulation Initiative

The Carbon Capture Simulation Initiative (CCSI) is USDOE/NETL lead initiative that will develop and deploy state-of-the-art computational modelling and simulation tools to accelerate the commercialization of carbon capture technologies from discovery to development, demonstration, and ultimately the widespread deployment to hundreds of power plants. A CCSI will provide simulation tools that will increase confidence in designs, thereby reducing the risk associated with incorporating multiple innovative technologies into new carbon capture solutions.

For further information go to:
www.acceleratecarboncapture.org/keywords/toolkit

It was put to them that the more powerful computational and simulation tools now being developed in the USA such as the Carbon Capture Simulation Intiative Tool Kit which developers can access could offer a route to dispense with one or more of these stages. Did they think, for example, that testing at the 10 MWe scale was really essential. Responses from the capture technology developers were mixed. While the merits of simulation were not disputed, many had reservations about skipping stages in the development process. But there was a feeling that simulation offered benefits that were currently not being realised. Perhaps tests could be shorter in duration? And simulation could make a greater contribution to optimising heat integration between the capture unit and the power plant. With costs continually under the microscope and as computational tools become more powerful, this discussion is sure to continue.

A thoughtful and informed discussion panel was held about the need for reconciliation between storage performance standards and the monitoring and verification methods to demonstrate conformance with these standards. A common public, policy, and regulatory expectation of a very high standard of storage performance (indicated by terms such as "no" leakage, "stabilized", "no migration") is in tension with technical limits on detecting small volume and slow leakage. These issues are especially significant with regard to monitoring to achieve closure. Policy, public acceptance, monitoring and risk assessment were components discussed. The original levels of performance in the 2005 IPPC Special Report were probabilistically designed and expressed a high level of confidence for geologic storage in a well selected and designed site with appropriate operation. The values discussed were not a performance standard for assessing project performance and did not refer to a single project but rather an ensemble of projects. Over time, the CO_2 retention values discussed in the IPCC (2005) report unintentionally sometimes came to be used as indicative of performance standards, even though they were never intended to be used for this purpose.

The Aquistore site is the largest field laboratory in the world related to the measurement, monitoring and verification of injected CO_2, and in 2016 two full seismic runs using various technologies – a 650 geophone seismic array, vertical seismic profiling (VSP) and distributed acoustic sensing (DAS) – imaged the injected CO_2 at a depth of 3.2 km.

Vibroseis trucks lined up to provide seismic sources at Aquistore (Image and boxed text courtesy of Norm Sacuta, PTRC)

The task for monitoring now seems to have become to prove that no leakage is occurring, in other words, "proving a negative", which is a notoriously difficult task. For example, one problem is that relying on a pre-injection baseline is challenging because the baseline can shift over time. However, deviations from baselines are now written into regulations. If a high performance standard is sought, the risk of false alarms and possible project shutdown increase. Discussion points included distinction between CO_2 retention, impact on climate change from avoiding emissions, human health and safety. A single metric about CO_2 retention is not a good proxy for any of these risks. The leakage mechanism, leakage pathway, and receptors need to be considered when assessing risk. A number of strategies for dealing with leakage risk were discussed, however the general conclusion was that leakage rates are low and manageable. Pragmatic approaches for designing monitoring programs that balance costs and benefits are needed.

The progress of emerging CO_2 capture technologies for combustion-based power generation systems was discussed during the session "Will advanced technologies reduce the cost of capture?".

Amine Scrubbing was taken as the capture benchmark, to compare the other technologies against. PCC was considered by its proponents to be a "hard to beat" moving reference, as it is improving all the time by reducing thermal energy penalties and by addressing impurities and minor emissions at a level of detail that should be matched by emerging technologies.

Water-lean solvents are considered by some developers to be the future of CO_2 Capture because of their theoretical advantages and their capability to use proven absorber/stripper systems. This should facilitate future testing of new advanced solvents in pilot plants at relevant scale.

Other developers point to the known theoretical benefits and recent developments in scaling up solid sorbent systems for postcombustion applications. The large flow rates at atmospheric pressure seem to favour structured adsorbents and fluidised bed contactors. The later has progressed from TRL 3-4 to TRL 7 mainly at the Korea Institute of Energy Research with a pilot designed to treat 35000 Nm3/h (10 MWe equivalent) using a potasiun carbonate/ bicarbonate reversible reaction system involving interconnected fluidized beds.

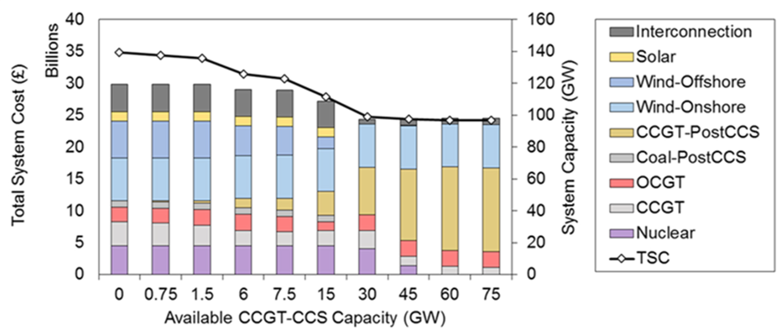
1.7MW Calcium Looping test facility at the La Pereda power plant in Spain where continuous testing has been undertaken over 1000's of hours at this scale. The next step is to scale the process up to the 20MW scale. Image courtesy of Carlos Abanades, CSIC.

The substantial recent progress on postcombustion Calcium Looping (from TRL4 to TRL6-7, mainly in Spain and Germany) was emphasized also using an interconnected fluidized bed system that involves capture of CO_2 with CaO and oxycombustion to regenerate CaO from $CaCO_3$. The energy input to the capture system is much larger than in any other PCC system, but the operation at very high temperatures allows for effective power generation using commercial CFBC boiler equipment and relatively mature oxycombustion components.

Chemical looping combustion (CLC) of solid fuels for power generation it is claimed behaves as a large scale CFBC boiler. CLC has many inherent benefits as there is no contact between the fuel and the combustion air and no gas separation stage is required. Fuel particles are oxydised to CO_2 and H_2O(v) by a solid oxygen carrier previously oxidized by air at high temperature. Since there is no need for much added equipment (other than CO_2 purification and compression) a potential to deliver a large reduction in cost and energy penalties are claimed. However, relatively modest progress in scaling up the technology beyond TRL4-5 has been achieved in recent years.

The benefits of polymeric membranes for postcombustion: such as simple passive operation with no hazardous chemicals handling, compact, low water use, modular (advance manufacturing offsite), highly flexible on turndown and ramp up and very efficient for partial CO_2 capture were discussed Pilot testing has recently gone up to 1MWe scale (TRL 6-7) in USA and other similar projects are in the pipeline.

Whilst it seems no firm conclusions were drawn, amine based PCC is still ahead of the field but other capture options are gaining momentum and we look forward to seeing how far these new capture options have progressed at GHGT-14.



Availability of CCS-equipped power plants reduces the total generation capacity required to meet demand and also the total system costs (TSC) for the future UK grid (cite, 201x), highlighting one measure of the value of CCS in future energy systems.

Image courtesy of Niall Mac Dowell

The discussion panel on Creating Value for CCS in Future Energy Systems, **explored the impacts of government policies and shifting markets on the potential for CCS deployment, metrics of the value of CCS in different applications, and future directions for technology innovation to better position CCS in new markets. Most analyses on CCS implicitly (or explicitly) assume carbon pricing driving adoption of CCS, but that many governments are pursuing a mix of policy instruments (e.g., emissions performance standards, baseline-credit mechanisms, and sector-specific lifecycle emissions standards). The impact of mechanisms other than carbon pricing has implications for how CCS is valued which hasn't been fully explored. Moreover, change is happening quickly in the electricity generation sector in terms of competing electricity generation, energy storage, and demand side management technologies and market structure. These changes mean that, while fossil-generation equipped with CCS remains an important tool to achieve emissions reductions, other options are increasingly competitive. At the same time, there has been a growing interest in CCS for varied industrial applications – such as iron and steel, cement, etc. – reflecting the recalcitrant nature of emissions from these sectors. And, most recently, a surge in interest in negative emissions via bioenergy systems with CCS (BECCS) and even air capture. One point made in the discussion was that alternative mechanisms to finance CCS projects have become increasingly important. In the US, Section 45Q tax credits (i.e. credits against federal tax obligations for storing CO_2) in combination with enhanced oil recovery have played an important role. CO_2-EOR has been the value driver for most CO_2 capture projects not only in the US globally and that only 5 of the current 21 projects were driven by emissions reduction goals. Another observation was that the strengths and weaknesses of CCS seem well understood, the CCS community needs to better identify the opportunities and keep an eye out for threats. Another point picked up is that CCS is not just about the power sector but plays a role in multiple sectors and that there are a range of competing options to reduce emissions (even in industry). It was noted that CCS could contribute to emissions reduction in the domestic heating sector and there was a need to better frame the systems level benefits of CCS.**

Around the GHGT event itself there were a number of additional meetings, such as project progress meetings, etc. One of particular relevance to the conference was co-hosted by Bellona on the topic of BioCCS and Negative Emission Technologies. IEA Bioenergy launched a special project on the role of Bio-CCS in climate change mitigation in 2016. A workshop was held as a side event during GHGT-13 on the topic of sustainability and GHG impacts of Bio-CC(U)S. A main point of discussion was the importance of Bio-CCS in scenarios that limit global warming to 2°C or even below, i.e. 1.5°C. Both IPCC and IEA have identified Bio-CCS as an important tool to achieve these mitigation pathways. However, the negative emissions potential might be negatively affected by a lack of sustainability, i.e. emissions associated with land use change, biomass production, biomass pre-treatment, biomass transport and biomass conversion technology. A key message from the workshop was that carbon negativity of Bio-CCS depends on the sustainability of the whole chain. Thus, related policies need to consider the environmental, social and economic feasibility of this mitigation option.

Bellona Bio-CCS Workshop at GHGT-13 (Credit: Bellona - Photo: Johan Verbeek Wolthuys)

What was New?

A new theme at GHGT-13 explored the potential of combining **CCS and Geothermal Energy.** There are different ways in which geothermal energy might be used. One concept that is most advanced is the co-location of a conventional fossil fuel power plant with a geothermal source. The geothermal source would provide heat the capture plant reducing the energy demand and improving the energy conversion efficiency of the power plant. Initial modelling suggests overall operational costs could be reduced leading to a lower levelized unit cost of electricity compared to a power plant with no additional contribution from geothermal energy.

Value of CCS

Papers on the modelling of the integration of CCS into power systems were presented at the conference for the first time. Flexible CCS plants have the potential to complement variable renewable inputs to a grid. The work has shown the value of CCS technology, to a grid going far beyond that implied by traditional levelized cost of electricity metrics (LCOE). The challenge is to communicate this long-term value to key decision makers who are accustomed to seeing and thinking in terms of LCOE metrics.

Japan CCS have produced 2 comics on CCS that were available at GHGT-13 in an attempt to engage younger generations in the world of CCS.

Left: 'Technology for the future of our planet'

Right: 'Beautiful Earth - Our Planet, Cartoon Explaining "CCS"'

(Both comics are available at the following website: www.japanccs.com/?library_category=print&lang=en)

Knowledge Transfer through Data Sharing

GHGT is not just about presenting results but two groups took the initiative to use the event to organise the launch of sharing projects' datasets for wider use by the CCS community, one deep-focussed, one shallow-focussed.

Geoscience Australia and CO2CRC launched the release of data from their controlled-release site at Ginninderra, near Canberra. Their research site has enabled scientists to simulate release of CO_2 from the soil into the atmosphere under controlled experiment conditions, and to assess the performance of different monitoring technologies, including airborne surveys.

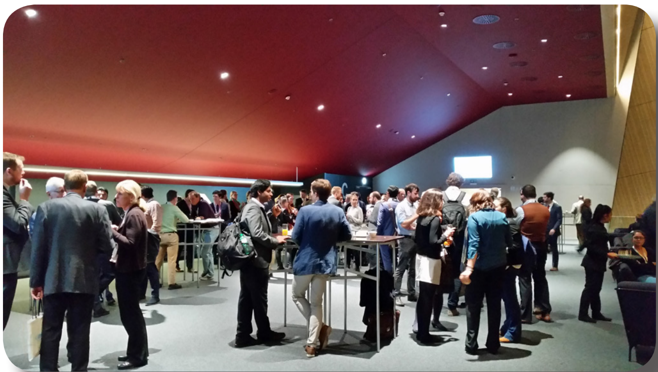
The CO_2 Storage Data Consortium (CSDC) was also launched. This is a new international collaboration for sharing reference datasets from CO_2 storage projects in deep saline formations. To increase efficiency of building capacity, confidence and competence in CO_2 storage, the CSDC is developing a platform for sharing datasets from pioneering CO_2 storage projects. Access to well-understood data should accelerate the development of new site characterization methods, reservoir simulation and monitoring technologies.

"These two great initiatives in sharing data, should help to facilitate wider learning from projects and so to assist CO_2 storage developments around the world." Tim Dixon, IEAGHG

Student Reception

The GHGT conference organisers recognise the contributions made to todays' technology developments by students. Not only are they conducting essential research and lab scale experiments but they also form the future workforce and decision makers. At GHGT-13, as in previous conferences, a Student reception was organised acknowledge this contribution by bringing together the attending students and a number of selected experts to forge working collaborations in a relaxed and friendly atmosphere.

With sponsorship from GE, the student reception attracted 100 students including IEAGHG Summer School Alumni who were able to catch up and discuss their progress. Presentations reinforced the role the students will play in the development of CCS and encouraged them to take advantage of the networking opportunity provided by the reception.



Closing Panel

To bring the conference to a conclusion the closing panel addressed the topic of Driving CCS Forward in a below 2^{0}C World.

The panel felt that CCS does not see itself as a competitor to renewables but a complementary low carbon technology in any power system because of the high variability of renewables electricity supply. However, they felt that the reverse was not true.

A key message from the conference was therefore that: ***If we are going to achieve the goal set at Paris we are going to need ALL low carbon technologies, and mitigation in ALL sectors not just power and industry.***

After much debate the recommendations of the closing panel to the broader CCS community and beyond were:

- ***Incentives are crucial*** - Post Paris targeted support in the form of incentives are needed to advance CCS.
- ***Infrastructure development is essential*** - A critical objective is to develop the transport and storage infrastructure to allow large quantities of CO_2 to be injected and stored offshore in regions like Europe initially.
- ***Innovation is needed*** to drive down the costs of CCS and make it competitive in the market place with other low carbon technologies.
- ***Industry has a key role*** - The Oil and Gas Industry has the skills and expertise to help develop a CO_2 transport and storage framework for the future.
- ***Information exchange is critical*** - The CCS research community has a lot of Information but we need help from communication experts to better frame the messages to stakeholders

The Panel concluded that If we get these actions right, we can drive the Implementation of CCS forward in the coming years.

Finally, the panel considered CCUS, apart from CO_2-EOR, CCUS does not involve permeant storage and is therefore not a technology that will contribute (except in niche applications) to reducing global greenhouse gas emissions to meet the below 2^{0}C target.

Greenman Award

Piece courtesy of www.llnl.gov/news/friedmann-receives-greenman-award

Lawrence Livermore National Laboratory (LLNL) energy guru Julio Friedmann has been honored with the Greenman Award (**www.ghgt.info/greenman-award**) at GHGT-13 in Lausanne, Switzerland.

Friedmann is recognized for his tireless efforts to promote CCS, particularly at large scale. This award is given to those who have made career-scale impact on the management of CO_2 removal, storage and utilization.

"I am honored to join the prior recipients," Friedmann said. "The award stands for accomplishment. I feel pleased that so many people believe I have accomplished something in the energy sector."

The Greenman was chosen to represent these achievements as it is an ancient archetype of a human face peering through growing foliage, which is often depicted on buildings, churches and cathedrals. It symbolizes the mysteries of creativity, compassion, healing, new beginnings and especially man's connection with nature and the power of humankind working together with nature, the cycles of creation and "man and the forest."

The Next GHGT...

The location of the next GHGT conference is widely accepted as the worst kept secret in CCS, however, this time a few red herrings did the trick and the announcement of Melbourne, Australia as the next host seemed to surprise most.

Paul Feron, CSIRO took to the stage to paint the CCS picture in Australia and to invite the audience to bolster their airmiles and join the conference 21st - 26th October 2018.

Australia is rapidly becoming a very exciting place for CCS. By the time of GHGT-14 Gorgon should be online and have significant results.

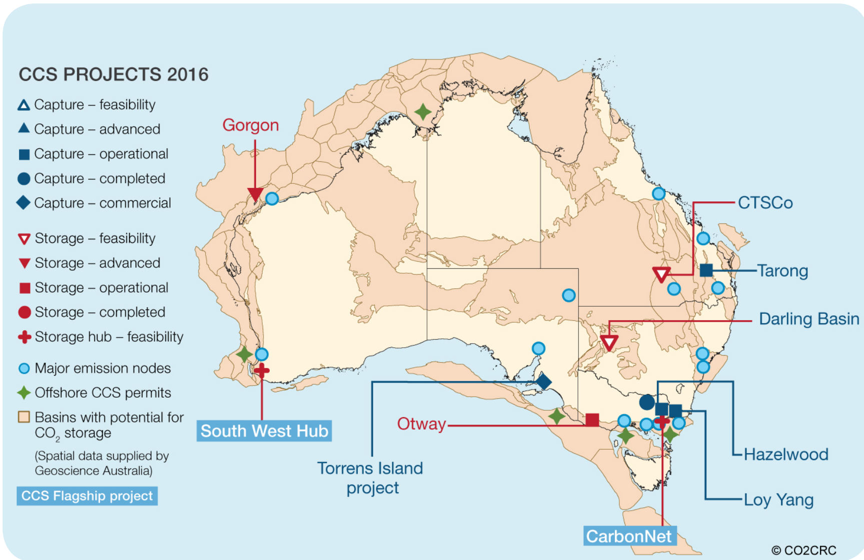


Image: Andrew Fietz – CO2CRC

In addition to Gorgon, Australia also has:

- 3 operational capture projects;
- the Otway storage site which we hope to be able to offer tours to;
- the publication of the new road map for CCS in Australia;
- renewed political support for CCS.

The venue will be the Melbourne Convention and Exhibition Centre which is just on the edge of the CBD and sits on the river Yarra. With over 5000 hotel rooms within walking distance of the centre and Melbourne's tram service (which is free to use within the CBD), getting about is simple, quick and fun. The weather for October tends to be in the early 20's^{0}C so very pleasant for what for many of us would be autumn days.

Travel to Melbourne is simple (although not short), with a large selection of airlines servicing Melbourne and options to transit through Dubai and Asia.

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