ghgt-16

16 th GREENHOUSE GAS CONTROL TECHNOLOGIES CONFERENCE

23 - 27 OCTOBER 2022

Conference Summary

ORGANISED BY

ieaghg

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TABLE OF CONTENTS

GHGT-16 STEERING COMMITTEE MEMBERS

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Nicolas Castel, IFPEN
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GHGT-16 BACKGROUND

Palais des Congres de Lyon, Lyon

GHGT-16 was held in the French city of Lyon which has one of the largest Renaissance quarters in Europe and boasts a 2,000 year old UNESCO world heritage site. Delegates were treated to the city's famed gastronomic cuisine. The Lyon Convention Centre has been designed to be environmentally harmonious. It boasts 24,000 m^2 of flexible meeting spaces including three amphitheaters plus 35 fully equipped meeting rooms.

Delegates enjoying social activities at the Gala Dinner at La Sucrière

GHGT-16 was hosted by Club CO_2, the leading French CCUS team, supported by four major and well-recognised institutions: ADEME, BRGM, IFPEN and TotalEnergies.

At the conclusion of the conference the hosts organised two specialised field trips. One group visited IFPEN's CO_2 capture testing facilities in its premises in Solaize. Dedicated tests can be done at this facility to evaluate the performance of new processes. The second leg of the visit was to the CimentAlgue industrial research project based on a consortium of Vicat (French international cement group), AlgoSource Technologies, TotalEnergies, and the University of Nantes CAPACITÉS facility. The aim of the project is harnessing captured CO_2 and waste heat, sourced from the manufacture of cement, to produce microalgae.
An alternative group, organised and guided by BRGM, visited the Limagne d'Allier basin, close to Clermont-Ferrand west of Lyon. The region is an excellent area to observe natural CO_2 migration through faults into rivers and groundwaters as well as its impacts on the local environment.

River Allier and *European Natura* 2000 site, a protected area that includes natural CO_2 springs, visited as part of the BRGM organised post conference field trip. (photo by James Craig)

ABOUT THE HOSTS

Club CO_2 is committed to developing capture, transport, utilisation and storage technology which is one of the key solutions for reducing CO_2 emissions and concentrations in the atmosphere.

ADEME has been involved in the fight against climate change and the degradation of resources for 30 years. The organisation is committed in its determination to shift the effort required to build a more resource-efficient and inclusive society.

IFP Energies nouvelles (IFPEN) is a public research, innovation and training organisation in the fields of energy, transport and environment. From research to industry, technological innovation is central to all its activities.

BRGM, the French geological survey, is France's leading public institution for Earth Science applications for the management of surface and sub-surface resources with a view to sustainable development. Under partnerships with numerous public and private stakeholders, BRGM focuses on scientific research, expertise and innovation. Its activities meets four objectives:

- understanding geological phenomena and related risks,
- developing new techniques and methodologies,
- producing and distributing data for surface, subsurface and resource management,
- providing the tools required to manage the surface, subsurface and resources, prevent risks and pollution, and manage policies in response to climate change.

TotalEnergies is a broad energy company that produces and markets fuels, natural gas and electricity. Its 100,000 employees are committed to better energy that is more affordable, more reliable, cleaner and accessible to as many people as possible. Active in more than 130 countries, its ambition is to become a responsible energy major.

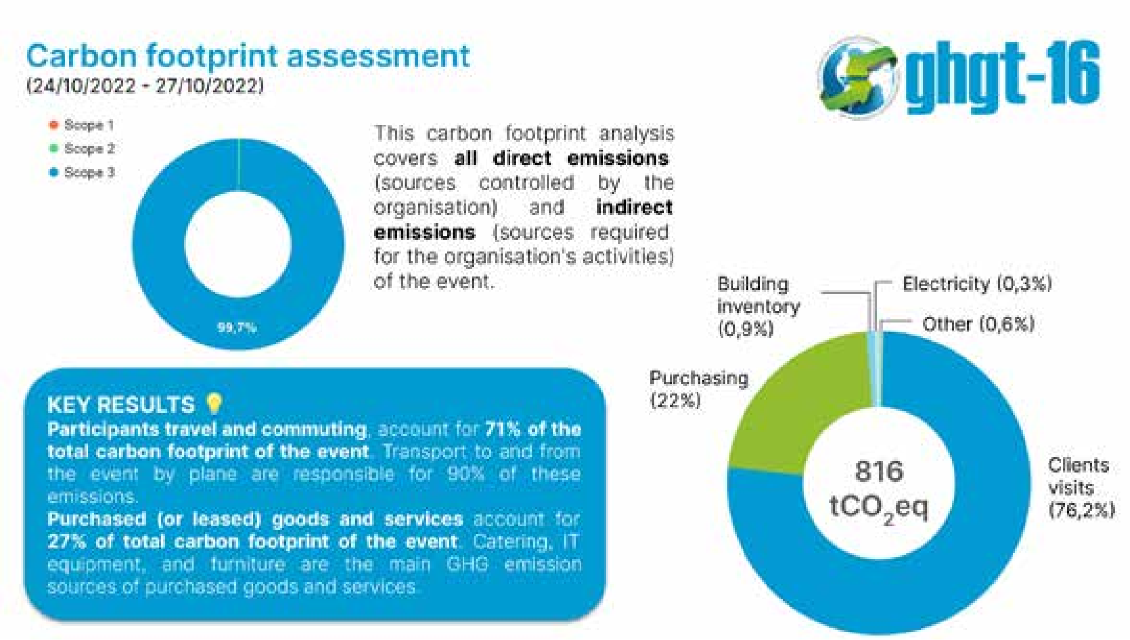
GHGT-16 STATISTICS & IMAGES

GHGT-16 CARBON FOOTPRINT

A Carbon Footprint assessment was conducted by Aktio (www.aktio.cc) and covers all direct and indirect emissions, prior to, during and following GHGT-16 and includes equipment, communication, travel, accommodation, and catering. The total GHG emissions are estimated at 816.36 tCO_2eq., this is an equivalent amount to that captured and stored by a typical CCS project in 8 hours of operation.

- Participants travel and commuting account for 71% of the total carbon footprint. 96% of this is attributed to transport to and from the event, 2% to transport during and 2% for accommodation.
- Plane transport was responsible for 94% of the carbon emissions to and from the event (64% of the total emissions), other modes of transport include bus (26%), train (16%), car (3%) and electric car (0.2%).
- 27% of the carbon footprint is from purchased goods and services, the main sources being catering (31%), IT equipment (29%) and furniture (18%).
- The remaining 2% is spread over variety of sources including capital goods, waste, electricity, and goods transport.

The emissions will be compensated for. The detailed information from Aktio will be used to further reduce the carbon footprint of the next GHGT conference.



GHGT co-chairs Florence Delprat-Jannaud (Club CO_2) and Tim Dixon (IEAGHG) welcoming delegates to the drinks reception at the Palais de la Bourse.

SETTING THE SCENE: KEY POINTS FROM PLENARY SESSIONS

WELCOMING ADDRESSES

Kelly Thambimuthu, Chairman of the IEAGHG Programme (custodian of the GHGT conference series), kicked off proceedings by welcoming delegates to this conference, the 16th in the GHGT Series with the inaugural held back in 1998. Dr Thambimuthu thanked the local hosts of this conference, ClubCO$_2$, ADEME, IFP Énergies nouvelles, BRGM, TotalEnergies and the platinum, silver and other sponsors, without whom this conference could not go ahead. He recognised the importance of focussing on scientific and related technological solutions for climate change mitigation. The recent IPCC Sixth Assessment report, and the 2021 IEA report on net zero, both stress the importance of CCS, plus BECCS and CCUS, as they provide an essential 25% contribution towards meeting the net-zero target by 2050. Kelly emphasised the high profile of the GHGT conference series, including this one, as a showcase of recent research, achievements and opportunities in the world of CCUS.

In her welcoming address **Florence Delprat-Jannaud**, Chair of ClubCO$_2$, also stressed the significance of GHGT as, 'the largest and most important conference on CCS and CCUS technologies', and noted the key role the host country, France, has played in deploying climate mitigation technologies particularly since the adoption of the Paris Agreement in 2015. She further observed that CCS, CCU and energy transition is a complex process. The objective of GHGT is to share knowledge, and now 'it is time for action' and 'we have to go faster, wider, together' to reach our climate goals.

Tim Dixon, General Manager of IEAGHG, enthusiastically thanked the hosts particularly for bringing the GHGT conference to France for the first time. The event attracted 1,200 delegates and received over 800 abstracts. In total the conference included 350 oral presentations plus 300 posters delivered via 7 parallel sessions.

IEAGHG Chairman Kelly Thambimuthu welcomes delegates to GHGT-16

KEYNOTE ADDRESSES

Thelma Krug, Vice Chair of the IPCC, has played a key leadership role in the outputs of the IPCC. Thelma recognised the unequivocal human influence on the warming of the atmosphere, oceans, cryosphere and biosphere, which has reached an unprecedented rate of warming since 1970. The phenomenon has led to a consistent expansion of policies to address mitigation since the Fifth IPCC Assessment Report in 2014. The initiative has led to the avoidance of emissions, however, policy coverage is uneven across different sectors. The IPCC Sixth Assessment Report has also highlighted the current pledged nationally determined contributions (NDCs) are not enough to limit global warming to less than 1.5°C. Moreover, global rates of CCS deployment are far below those included in modelled pathways for reaching <1.5°C warming. As Dr Krug asserted, 'the evidence is clear: the time to act is now'.

Mary Burce Warlick, Deputy Executive Director of the IEA, expressed how encouraging it was to see so much interest and support in CCUS from the attendees of the conference. The IEA's 2021 roadmap for net zero noted that CCUS is one of the key pillars for reaching net zero. Its deployment to capture 7.6 Gt of CO_2 by 2050 is an ambitious scale up but essential in many areas. In some sectors it will not be possible to achieve net zero without CCUS. Despite its importance, CCUS is not on track for net zero by 2050. However, recent favourable policy support in the USA, Canada and the EU does show promise. Mary stressed the necessity for robust regulatory frameworks worldwide to ensure safe, secure, and permanent CO_2 storage in geological formations. The GHGT conference series is an important forum to discuss the needs and opportunities in the world of CCUS.

Finally, **Jarad Daniels** CEO of the Global CCS Institute, echoed the significance of CCUS as an essential tool for reaching net zero and as a sustainable pathway forward. Demand drivers for CCS include net zero commitments from governments and businesses, plus the need for low-carbon footprint commodities. Economic drivers also need to include growth and prosperity. Recognition of the technology's growth is highlighted in GCCSI's latest report. There are now 30 operational CCS projects worldwide along with 61 currently in development. Realising CCS at a global scale will need a long-term drive and a high value placed on CO_2 storage. Support for storage resource appraisal, backed by CCS-specific laws and regulations to enablement investment in CCS through policy and market mechanisms, will be essential. Jarad concluded by noting that 'net zero by 2050 requires strong action by 2030, and the installed capacity of CCS needs to increase 100-fold by 2050 to meet global targets'.

For more information on the publications and organisations noted in these keynotes, please see the below websites:

www.ipcc.ch

www.iea.org

www.globalccsinstitute.com

www.club-co2.fr

PLENARY 1

The second day of GHGT-16 started with a Technical Plenary introduced by Florence Delprat-Jannaud of Club CO_2. The first speaker was **Christine Healy**, Senior VP, Carbon Neutrality and Continental Europe, and a member of the EP Executive Committee (CDEP) for TotalEnergies.

Christine began by stressing how carbon neutrality and CCS is critically important and how vital it is to deliver projects on time, on budget and safely. She impressed the importance of working together towards that goal. Recognition of the environmental consequence, and cost of delivering global energy requirements, clearly shows that CCS is a key part of that remit.

As a company TotalEnergies has a vision to achieve net zero by 2050, together with society, continuing their historical involvement in oil and gas but recognizing that this will just be a part of the mix going forward. The corporate strategy is for 50% renewables, 25% new molecules and 25% oil and gas. Because oil and gas will be part of the portfolio, CCS also needs to be considered as part of a triple punch strategy of avoidance, reduction, and compensation. CCS is a solution for both site-specific projects and hub development to take CO_2 from customers, transport and store on their behalf. Other goals include the curtailment of routine flaring, improvement in energy efficiency, and increased green power covering all industrial sites.

To deploy CCS strategy and move forward every project will have to meet highly stringent standards from an emissions perspective. Examples include Papua New Guinea LNG, North Field East and South (Qatar), Ictus (Australia), and Cameron LNG (USA). TotalEnergies are offering Carbon Transport and Storage services business with the aim of building a profitable, scalable enterprise centred on the North Sea as a core area. Christine stressed the enormity of the task and the sheer magnitude of investment required to achieve successful delivery.

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Christine outlined three projects in varying degrees of completion that TotalEnergies are involved in. The Northern Lights project, in Norway, is a storage opportunity that is very attractive to their customers. It validates the existence of a market with the potential for expansion. Aramis, in the Netherlands is a joint venture for transportation with storage in depleted gas fields. The infrastructure is also in good condition. The company is already looking at Phase 2-4. Lastly the NEP project in the UK has offshore infrastructure and storage in the Endurance field.

Lastly, Christine spoke of an issue that she is asked about all the time. ‘What are the policy drivers that need to be in place to drive CCS forward?’ She explained that investors need predictability and stability, especially with projects with 20-year duration and a post-injection monitoring phase.

With such a long cycle, investors need to be convinced to accept risks over the long term and that requires stability. Once a policy is put in place, it's important that it remains consistent. Otherwise, potential uncertainty could mean it will be difficult to make decisions. For an industry in its infancy, companies and investors may become risk adverse. It's apparent that clear business models will emerge with time from the variety of models at present. Christine wrapped up by recognising that there is an inflection point and the future of CCS is before us.

Dr Jennifer Wilcox is the Principal Deputy Assistant Secretary in the Office of Fossil Energy and Carbon Management at the US Department of Energy, and started at the DOE under the Biden-Harris administration. Dr Wilcox introduced the role of carbon management in achieving net zero goals. The Department of Fossil Energy has recently added Carbon Management to its title, an intentional move to show the direction of travel with a new vision of: 50% emissions reduction by 2030; CO_2 emissions-free power sector by 2035; and net zero emissions economy by no later than 2050. New legislation, including the Bipartisan Infrastructure Law (BIL), has allocated $12 billion for carbon management – laying the groundwork for action. This policy initiative is designed to set up first-of-a-kind projects and stimulate learning by doing, and industry investment is required to achieve goals and make it economic. Secondly, the Inflation Reduction Act (IRA) has been established, which includes the 45Q federal tax credit enhancement for carbon removals. These offer two levers - infrastructure and policy – both critical to move forward.

Jennifer outlined the three areas of particular focus that reflect a multi-dimensional facet to CCS development. In addition to CO_2 storage, methane mitigation will be necessary plus environmental and societal justice. The Bipartisan Infrastructure Law comes with strings attached to address societal impacts. The community benefits plan represents 20% of the score of each application with four key priorities: stakeholder engagement, understanding the concerns and acting on those concerns; diversity, equity, inclusion and accessibility, vital in recruitment; Justice 40 Initiative with 40% benefit to disadvantage communities; and quality jobs. These four will be part of every application.

Jennifer recognised that public perception is important and although CCS is not new, the public perception is that it is, despite 20+years of DOE research and 12 Mt CO_2 permanently stored. The generation of mixed messages requires clarity especially when it comes to environmental safety record and the implementation of regulations that are rigorous.

PLENARY 2

Two high profile CCS champions, **Ruth Herbert**, Chief Executive of the CCSA and **Matt Crocker**, Senior Vice President of Low Carbon Solutions ExxonMobil, gave different perspectives of the considerable scale-up in the technology. This second of GHGT-16's Technical Plenary was chaired by IEAGHG's General Manager, Tim Dixon.

Ruth's presentation, entitled "UK Development – Clusters & Business Models" outlined the UK's ambitious plans, published in "Net Zero Strategy: Build Back Greener", October 2021, to develop a series of CCS hubs. The strategy has set out a plan to capture 20-30 Mt CO_2 by 2030 rising to over 50 Mt CO_2 by 2035. There is a commitment to develop four CCUS clusters with at least two operating by the mid-2020s and storing 53Mt/yr by 2035. There is a CCS Infrastructure Fund now totalling £1 billion plus an interim goal of 1 GW of CCUS-enabled hydrogen by 2025, aided by a £240 million Net Zero Hydrogen Fund. The initiative forms part of UK's target to reduce GHG by 78% by 2035. Current progress in 2022 shows that these plans are now a year behind. There are five key coastal locations around the UK that are well suited to industrial CCUS hub development where there are clusters of large concentrations of industrial CO_2 emissions from oil and gas (O&G), petrochemicals, steel and power plants.

Two clusters, HyNet, which will have access to geological storage offshore in Liverpool Bay, and East Coast Cluster off the east coast, have reached Track 1 stage. The Scottish Cluster in north-east Scotland is a Track 1 reserve. Storage capacity in both depleted O&G fields and saline aquifers is already advanced. In September 2022 a Carbon Storage licensing round attached 26 bids. Licenses will be awarded in 2023 with first injection as early as 2027. Storage rates as high as 30 Mt a year by 2030 could be achieved. There are parallel developments in investment models and a Dispatchable Power Agreement (DPA) for power linked with CCS. An Industrial Carbon Capture (ICC) contract over 15 years would be set up for individual projects. Government co-funding would be available for initial projects. There is an intention to reduce subsidies as carbon prices rise and low-carbon product markets emerge. Carbon capture offered by a service company is also envisaged. A contract-for-difference (CfD) scheme is planned for hydrogen production based on a natural gas reference price. For BECCS and DACCS, a negative emissions payment mechanism is envisage to enable early projects, which, over time, will move to a Carbon CfD. Ruth concluded that targets will only be met if all capture commitments, now emplaced to meet the 2035 target, progress. Although there is some uncertainty in these plans the UK does have a successful track record from the development of offshore wind since 2012. The lessons learnt from this experience are invaluable for CCS.

The second half of the plenary took the format of an armchair discussion between Matt Crocker and Tim Dixon. Matt, who went to school in Cheltenham, the home of IEAGHG, has been with ExxonMobil for 27 years. Having worked on both up and downstream businesses in chemicals, Matt now heads the company's low-carbon solutions business. Tim prompted the question why did ExxonMobil set up a low-carbon solutions business in 2021? Matt stressed that it was part of the company's commitment to NetZero by 2050. This shift in direction will lead to the production of low carbon hydrogen and low emission fuels. It will need a $US 15 billion investment into low carbon products. One good reason for the policy is that CCS is proven and scalable especially for hard to abate sectors like cement and steel.

ExxonMobil is in the process of developing a new project in Louisiana, USA. It will be based on a first-of-a-kind (FOAK) commercial contract with CF Industries who are a fertilizer manufacture that produces ammonia and 2Mt of CO_2 a year. ExxonMobil will capture, transport and store CO_2 in an onshore site in a south-western part of the state which should be operational by 2025. Subsequent storage could go offshore.

Potential for CCS expansion along the Gulf coast is immense. The Houston area, for example, has a high concentration of industrial CO_2 emissions. By 2040, 100Mt/yr could be captured and stored. Hub development would be a series of projects, for example, around ExxonMobil's Bay Town complex, which is one of the world's largest industrial conglomerations. Multiple storage sites will be necessary given the shear scale of emissions. ExxonMobil also have a stake in five western European petrochemical and refining operations including Normandy (France), Antwerp (Belgium), Porthos (The Netherlands), Acorn (Scotland) and at the Fawley Refinery near Southampton, UK. In the Asia-Pacific region, ExxonMobil have interests in depleted O&G fields, in Australia, Indonesia, Malaysia and with a Chinese consortium.

Big multinationals, like ExxonMobil, have set clear and ambitious targets for achieving low-carbon emission targets via CCS. They have the means and skill to reach these goals. Similarly with targeted government support in the UK there is very significant potential to achieve genuine and permanent carbon emission reduction using offshore storage.

PLENARY 3

The third technical plenary at the GHGT-16 conference explored the challenges of CCS in two contrasting resource-rich countries: Australia and Indonesia, and was chaired by Philip Llewellyn of TotalEnergies.

Matthias Raab, the Chief Executive Officer for CO2CRC, opened the plenary with an overview entitled "CCS in Australia's transition to a low emission future". He was followed by Mohammad Rachmat Sule, the Manager of National CoE for CCS/CCUS at Institut Teknologi Bandung, Indonesia. Both speakers outlined how their respective countries were implementing a series of initiatives to progressively decarbonise their economies. This is a significant challenge as both countries' economies are heavily dependent on their mineral wealth and, in the case of Indonesia, still predominantly reliant on domestic fossil-fuel derived energy.

Matthias stressed that the world needs to decarbonise but not defossilise. There is a strong dependence on CCS technologies to achieve this goal but they need to prove that they are safe, reliable and necessary. What is clear is that CO_2 storage is immediate, permanent and can be operated at very large scale. Moreover, recognition of the economic value of CCS can be demonstrated when the cost of emitting CO_2 exceeds the cost of CCS implementation.

Australia's rapid progress with CCS is apparent from the 14 projects which have reached a feasibility stage by 2022. AUS$250M has now been committed in investment. The country is a big LNG exporter which has significant implications for large-scale CO_2 storage. Australia's north-west shelf has significant LNG potential. CO_2 from these fields could be injected into Timor Leste's Bayn-Undan depleted gas field which is in the adjacent territorial shelf area. Within the next 5 -15 years there will be more large-scale project roll-outs, however, nothing is guaranteed. There is an acknowledgement within industry that a 43% reduction in carbon emissions needs to be achieved by 2030 if the 2050 net-zero target is to be met.

One of the many complications facing the country are its CCS regulations. There are variations between states and the Federal framework is over 15 years old. There are omissions with respect to ACCS credits for some options including CO_2-EOR and DACCs. Regulators are not necessarily fully conversant with CCS and CCUS technologies or the latest and most effective monitoring techniques.

One area where the Australians have made an impressive impact is their contribution to R&D, particulary in the field of subsurface CO_2 monitoring. At the forefront of this drive is the Otway International Test Centre which has been responsible for breakthrough technologies. These include the post-injection monitoring which has successfully tracked a CO_2 plume by using 4D surface seismic. The development of stationary orbital vibrators, in combination with distributed acoustic sensors (DAS), has enabled rapid acquisition of subsurface signals to detect the plume using transects. Vertical fibre optics can image as little at 300 tonnes of CO_2 using time lapse techniques in only two days. However, the technology took 10 years to develop and has to be clearly demonstrated. A paradigm shift in cost reduction of 80%, in this monitoring technology has been achieved which is a considerable achievement.

In terms of storage developments Australia is planning CO_2-EOR partly because the country is 90% reliant on imported oil so there is an energy security imparative. Australia is also developing underground hydrogen storage by the end of the 2020s and DACCs.

Mohammad Rachmat Sule outlined how the role and commercialization of CCS/CCUS could meet Indonesia's Net Zero Emission Target.

The country's target for greenhouse gas reduction from the energy sector between 2010 and 2030 is between 314 and 398 M tonnes of CO_2. The gas could be captured from a number of natural gas fields and industrial sites but would be predominately derived from coal-fired power plants. There are 15 CCS/CCUS projects across the country which should come to fruition before 2030. The first storage project, in the Gundih Field, is scheduled for initial injection by 2027. Injection of 3 M tonnes of cumulative CO_2 is planned over 10 years. Storage potential in oil and gas (O&G) fields, estimated by LEMIGAS, could be ~2 G tonnes in O&G reservoirs and 10 G tonnes in saline aquifers. Emissions from the country's upstream and downstream O&G industries is projected to peak at 44 M tonnes by 2030 and then decline to ~12 M tonnes by 2060 as storage is implemented.

Draft ministerial regulations are under development with both internal ministries and a number of other international public and private institutions from eight countries plus the EU. These include, UK, USA, Australia, Norway and Singapore. The scope covers technical, business, legal and economic aspects. The proposed scheme allows either the government or a company to benefit from a carbon credit based system depending on the economics of an individual project.

This plenary highlighted the shear scale and ambition which both countries are advancing to meet their 2050 net-zero targets. The challenges are significant, but with sufficient political will and drive decarbonisation, at scale, could be achievable.

CLOSING PLENARY

The final day of the 16th Greenhouse Gas Control Technologies Conference (GHGT-16) in Lyon, France saw the conference delegates embark on a live virtual tour of the Northern Lights Project.

The Northern Lights (a partnership between Equinor, Shell and TotalEnergies) is part of Norway's Longship Project to develop the world's first open-source CO_2 transport and storage infrastructure. Construction began in 2021 and is still ongoing. This onshore receiving terminal on the Norwegian west coast will offer a safe and reliable shipping facility plus temporary storage services to industrial emitters from across Europe. With increased interest from industrial sectors in Europe, additional shipping and storage capacity will be developed as demand grows. Initially CO_2 will be transported from Fortum Oslo Varme's waste-to-energy plant at Klemetsrud, near Oslo, and Norcem's cement factory in Breivik on Norway's south coast.

From early 2025, 800,000 tonnes of CO_2 will be captured, compressed, and liquefied in the Netherlands, and then transported by ship to the terminal, from where it will be transported through a 100 km pipeline to be permanently stored at 2,600 metres under the seabed on the Norwegian continental shelf.

Progress with CCUS has conventionally been conveyed by policy/decision makers, activists, industry leaders, and from a project developer's standpoint. For the first time at a GHGT conference, and to provide a complimentary perspective, a Youth Panel was constituted. The panel, moderated by Nicolas Castel (IFPEN/Universite PSL), consisted of young professionals drawn from academia and industry namely, Saja Albaidarat (University of Sheffield), Sibylle Duval-Dachary (IFP Energies nouvelles), Athreya Suresh (The University of Texas at Austin), Miguel Abreu (The University of Texas at Austin) and Izaak Ruiz (Repsol). The panel delivered an informed, intellectually stimulating, and thought-provoking discussion to the global audience. CCUS was reaffirmed by the panel as a critical tool to curb global emissions and the CCUS community needs to make CCUS a bit 'cooler' to attract the younger generation.

The youth panel from Day 4 at GHGT-16

KEY POLICY & REGULATORY MESSAGES

- Investors need predictability and stability, especially with projects that have a 20+ year duration and a post-injection monitoring phase. With such a long operational cycle investors need to be confident that the associated risks over the long term are acceptable and that requires stability. Relevant policies must remain consistent otherwise potential uncertainty could make key decisions difficult.
- First-of-a-kind (FOAK) projects to demonstrate the effectiveness of CCS are essential to stimulate private sector investment, especially in regions or countries less conversant with storage.
- The global market for low-carbon steel products is not harmonised and there is no level playing field. European policy has to ensure that cross-border trading of steel products from outside the continent must have the same standards.
- Certainty on the availability of future hydrogen supplies is not clear and requires a policy directive. A revised investment policy does have global implications especially for renewable energy resources and the associated applications like hydrogen production.
- Northern Lights is the only storage project in Europe being constructed. If no new sites are developed soon there will be a 50% short fall in storage sites by 2030. A government led stimulus for transport and storage infrastructure development to meet future demand has been advocated.

CCS DEPLOYMENT

The Northern Lights integrated CCS project has now advanced to a construction phase. The project will bring captured CO_2 from Norcem's cement plant at Brevik, on Norway's south coast, and Hafslund Oslo Celsio waste incineration plant in Klemetsrud near Oslo. In August 2022 Equinor, the operator of the Northern Lights project, which also includes Shell and TotalEnergies, announced the successful completion of an exploration well that had been drilled into the target storage reservoir. Preliminary results confirmed sufficient storage capacity for Phase 1 and 2 of the project with at least 5 M tonnes per year. In the same month Northern Lights announced its first commercial contract, in addition to the Norwegian capture sites, with Yara Sluiski, an ammonia and fertiliser plant in the Netherlands to store 800,000 tonnes using Northern Lights facilities. In the final plenary at the GHGT-16 conference delegates were treated to a virtual tour of the Northern Lights facilities at the Energy Park in Øygarden municipality, near Bergen in Norway.

In 2022, there are 30 commercially operating CCS facilities, 11 facilities in construction and 153 in various stages of development. Many of these are in the United States which has introduced significant policies and laws, most notably the Inflation Reduction Act (IRA) which provides enhancements to the 45Q tax credit for CCS. It has been estimated that introduction of the IRA could increase the deployment of CCS by over 12-fold, equivalent to a storage rate of over 110 Mt per year by 2030.

ExxonMobil, for example, is in the process of developing a new project in the southern US state of Louisiana. It will be based on a first-of-a-kind (FOAK) commercial contract with CF Industries, a fertilizer manufacturer that produces ammonia and 2Mt of CO_2 a year. ExxonMobil will capture, transport and store CO_2 in an onshore site in south-western part of the state which should be operational by 2025. Subsequent storage could go offshore.

In Australia there are 14 CCS projects now in feasibility stages, plus one large-scale operational site, Gorgon. This impressive expansion includes potentially very large inter-linked CCS operations including CarbonNet in Victoria and a series of gas fields centred on Darwin in the Northern Territory. The north-west shelf assets could store CO_2 in Timor Leste's Bayu-Undan depleted gas field providing that country with a revenue stream. A recent appraisal of Australia's CO_2-EOR potential has identified a number of potential opportunities in the country's petroleum basins. For example, in the Cooper-Eromanga and the Bowen-Surat Basins an estimated 120 M tonnes of CO_2 could be stored producing an additional 250 M barrels of oil for a country that is 90% reliant on imports. Both these basins are in proximity to major emission sources.

RESEARCH AND DEVELOPMENT ACHIEVEMENTS - KEY HIGHLIGHTS

- **CO_2 capture from waste-to-energy (WtE) plants**, has confirmed the negative emissions potential in this area. For example, in 2019 AVR (Duiven, The Netherlands) installed a first of a kind commercial carbon capture plant in the WtE sector with a capacity of 100 kton/year. AVR uses 30 wt.% monoethanolamine (MEA) as the capture solvent. The captured CO_2 which is liquefied and transported is used for horticultural purposes, to enhance the growth of plants. In 2020 and 2021, AVR and TNO collaborated in the Dutch project MASTER (MAnagement of CO_2 capture Solvents Targeting cost and Environmental impact Reduction), where, the operation of the plant was monitored for two years to analyse its behaviour, optimize the operation based on the lessons learnt and propose solvent management strategies. During all campaigns, bleed and feed was used as solvent management strategy.
- **Japan CCS Co Ltd initiated a six year project in 2021 to design, build and demonstrate the ship transportation of CO_2** as a precursor to a much larger scale replication. Results will be used to develop business models for the purpose of CCUS. The demonstration ship, now under construction, will be a dual-purpose ship for transportation of liquefied CO_2/LPG. The specifications for a vessel with cargo tanks exceeding 60,000 m^3 has been determined and Approval in Principle (AiP) for the design has been obtained. Engineering, procurement and construction (EPC) for the shipping terminal is currently underway and is scheduled for completion by the spring of 2024.
- The conference session on **negative emissions included multiple greenhouse gases mitigation** (MGM). The concept is a co-removal of non-CO_2 (CH_4 and N_2O) greenhouse gases as well as CO_2 from the air. The focus is on energy efficient capture and conversion of CO_2, CH_4 and N_2O from the air closer to emission sources in the agricultural sector (for example: exhaust air from ventilation stables contains 20-300 ppm CH_4). This study is part of the project "energy efficient negative emissions from agriculture and farming" and funded by the Swedish Energy Agency. The process is designed based on thermal catalytic route for the methane conversion, which is coupled to a direct air capture unit for CO_2 capture.
- BRGM presented work on the variety of potential options possible of **combining CO_2 storage and geothermal energy** and the potential barriers to deployment, of which political barriers could be significant.

HYDROGEN & CCS FROM INDUSTRIAL SOURCES

- A techno-economic assessment of two low-emissions steel production technologies (equipped with CCS and hydrogen-based steelmaking) was conducted using the global multi-region, multi-sector Massachusetts Institute of Technology (MIT) Economic Projection and Policy Analysis (EPPA) model). The assessment, based on the current state of these technologies, found that the steelmaking equipped with carbon capture and storage increased costs ~7% relative to the conventional steel technology. In contrast, hydrogen-based steelmaking increased the costs by ~18% assuming hydrogen derived from steam reformation and linked carbon capture. If hydrogen was derived via electrolysis using renewable energy costs increased by ~77%. The EPPA model was enhanced to represent inter-sectoral linkages, demand responses, competition between technologies, and potential substitution with inputs in iron and steel production and other sectors of the economy.

- A novel and symbiotic CO_2 utilization process that exploits the residual gases from the steel industry (i.e., basic oxygen furnace gas (BOFG) and blast furnace gas (BFG)) for urea production has been demonstrated by the INITIATE Project. The coupling of these two manufacturing processes can be achieved by converting the residual steel gases into NH_3 and CO_2. The INITIATE process has reported the potential to reduce:
  - the primary energy intensity by 30%
  - the carbon footprint by 95%
  - the primary raw material intensity by 40% and
  - the waste generation by 90%.

- Sorption enhanced water gas shift (SEWGS) technology has been successfully demonstrated for CO_2 capture in iron and steel plants in the past. Now efforts are underway to couple it with indirect gasification of residual biomass to achieve negative CO_2 emissions while producing H_2.

GEOLOGICAL STORAGE OF CO_2

GEOLOGICAL CASE STUDIES

- The Surat Project in southern Queensland, Australia was the focus of how to effectively design a CCS Hub and how big it needs to be. With up to 30 years of emissions from Blue Hydrogen to ammonia plants, more than 10 emitters could potentially capture 5-10 M tonnes per year and would require a large storage site. Dynamic modelling was performed to evaluate injectivity over time and what is necessary to confidently achieve sustained injection to reliably store these volumes over time. Modelling suggests that to sustain injection rates of 5M per year would require 5 wells in 5 years, by 10 years you would require 40 wells and 77 wells would be required at 20 years.
- Stage 3 of the Otway project has been 10 years in the planning. This stage had a vision to deploy and field test a toolbox of innovative monitoring and verification (M&V) techniques and technologies for saline aquifer-based CCS projects. Signed off in 2019 it was completed in May 2021. Stage 3 focussed on pressure tomography and downhole seismic, and also tested earth tides, pressure inversion and passive seismic to better understand their application in an industrial context. The project successfully demonstrated the application of pressure tomography and downhole seismic which both accurately detected and located the plume in the subsurface in an economic way when compared to the 3D survey. These advances have immediate application to industry and the adoption of CCS.

- The Horda Platform in the northern North Sea provides both CO_2 storage capacity for the current design of the Northern Lights project (Aurora) and for future scale-up potential storage sites with a newly awarded CO_2 injection and storage licence granted in 2022 and two recently drilled CCS wells. A Containment Risk Assessment and Management (CRAM) performed on the Horda Platform storage sites and containment-related geological risks have been summarised. The top seal and across-fault seal related containment risks of CO_2 storage in the Jurassic aquifers are considered low due to good sealing potential of several caprocks. The along-fault flow risks of most faults are also considered low and reasons for these have been explored. The Øygarden Fault System has high across- and along-fault related containment risks and an onshore analogue (the Bjorøy fault zone) has been reappraised. The analogue has provided an insight into potential consequences of these risks. It is likely that there is stress decoupling between basement and overlying sediments which has implications for safety measure design and potential seismicity events.
- More detailed studies were presented on fault integrity with fault risk assessment workflows and fault characterisation methods explored at the Smeaheia fault block in the Horda Platform, offshore western Norway where the Vette Fault Zone is bounding the Alpha closure (a potential storage site for the Northern Lights Project). Modelling suggests that the leakage risk for CO_2 along the fault zone is low due to a combination of limited pressurization of the fault zone, clay rich sediments dominating in the fault, and limited fault thickness due to the low fault displacement in the overburden.
- As CCS scales up greater stresses will be placed on storage hubs in the near future. One consequence of this trend is the interaction of pressure plumes and possibly less flexibility to avoid risk receptors such as legacy wells. Another issue is the limited ability of CCS business models to support large and costly 3D/4D seismic surveys.
- In contrast to large-scale offshore storage in Europe the Czech-Norwegian CO_2-SPICER project, launched in 2020, targets Zar-3 a nearly depleted hydrocarbon field in fractured Jurassic carbonates. 3-D geological modelling has been completed with geochemistry and geomechanical studies underway. Risk assessment, including risk of leakage from legacy wells has been performed. A pre-injection monitoring program has been undertaken including background seismicity, soil gas and groundwater testing. The aim of this pilot project is to assess the storage potential, at a limited scale (100,000 t limit), with the broader objective of demonstrating implementation in the Czech Republic and elsewhere in central and eastern Europe.

DEPLETED RESERVOIRS & INJECTIVITY

- Depleted reservoirs are prime candidates for CO_2 storage and recent advances have improved confidence in storage capacity estimates and injection strategies. Modelling of the Sleipner plume by Equinor, for example, has highlighted the beneficial property of CO_2 as a contrast medium. The phenomenon can assist in mapping heterogeneities. Investigation has also shown that thermo modelling on the plume movement is essential.
- The Aramis project in the Netherlands is another example where a new workflow and related modelling has been used to estimate CO_2 storage resources within a reservoir. The injection of CO_2 has identified uncertainties within highly depleted gas reservoirs. This project has demonstrated the robustness of the injection strategy and the impact of subsurface uncertainties. The resultant reduction has improved the level of confidence for the storage resources with distinct well injection profiles.

STORAGE COSTS

- Recent work on the early-stage costs of storage project characterisation recognised the highest cost driver at this stage is 3D seismic. Although highly site-specific, it was observed that the area of seismic dominates the costs and it seems that the need for such facets is still often poorly defined.

- ARI's assessment of the impact of the 45Q tax credit system in the USA focused on the costs associated with monitoring, reporting and verification of geological CO_2 storage. Projects must demonstrate secure storage and compliance with Class VI and Class II wells plus other requirements. This investigation noted that additional costs can be accrued for compliance with applicable state regulations for saline storage and EOR. What is also evident, in all cases, are the incremental costs which are small compared to the overall project costs at less than $US1.50 per tonne.
- A key takeaway from the entire session on storage costs is the highly regional and extremely site-specific influence on costs.

GEOLOGICAL CASE STUDIES CO_2 MINERALISATION STORAGE

- The potential of utilising ultra-mafic rocks as potential CO_2storage through CO_2 mineralisation are at an early stage, but first steps in understanding available permeability and mineralisation pathways have been explored through a combination of laboratory and field studies with a focus on the Semail Ophiolite in Oman. Field scale linkages between serpentinization and carbon forming reactions from these locations, plus lab results, show a strong link between serpentinization and carbonate forming reactions at pore scale.
- Most field studies of subsurface basalt mineralisation are on fresh basalts, however altered basalts are more common. A study was performed to assess the degree to which naturally altered basalts are suitable for subsurface mineralisation efforts. The main take home messages are: that temperature has a marked effect on dissolution; that calcium is preferably released from altered basalts; and that carbonation of CO_2 injected into altered basalts at 100°C might mineralize within a few years of injection.

GEOTHERMAL SYSTEMS

- BRGM presented work on the variety of potential options possible of combining CO_2 storage and geothermal energy and the potential barriers to deployment, of which political barriers could be significant. Three significant KPIs are being used to assess potential models relative to a hypothetical project in the Paris Basin including: the amount of CO_2 stored over the lifetime of the storage site; environmental and safety indicators, for example, risk of leakage and induced seismicity; and economic indicators, the Net Present Value and levelized cost of storage. In addition, wider issues such as economic, political, societal, technical and geological factors are being explored and their influence evaluated on a case by case basis.

POST COMBUSTION CAPTURE

- Campaigns aimed at extremely high CO_2 capture rates were carried out at the MHI / KEPCO pilot plant and the Mongstad demonstration plant in Norway in 2021. Very high CO_2 capture rates of 99.8% were achieved in both the MHI/KEPCO pilot plant and the Norwegian Mongstad plant using KS-21TM solvent. The CO_2 concentration at the Absorber outlet was much lower than 400 ppm in air. This study has shown that the CO_2 capture cost would not increase much even compared to the conventional 90-95% CO_2 capture case in a typical CO_2 capture plant, even when the CO_2capture ratio increases to negative emission level. It should be stressed that these impressive capture rates were achieved at pilot plant scale and at a demonstration site.

HIGH TEMPERATURE SOLID LOOPING CYCLES

- Retrofitting partial oxyfuel and integrated Calcium Looping (CaL) technologies to existing cement plants has made significant progress. For example, the CLEANKER project has successfully demonstrated the design, construction and operation of CaL in Buzzi Unicem's cement plant in Piacenza (Italy) using CaL technologies for power-to-fuel-to-power systems.

The project's core activity is the design, construction and operation of a CaL demonstration system. CO_2 is captured from a portion of the flue gas of the cement plant and then uses the same raw meal as CO_2 sorbent that is used for clinker production.

CO_2 UTILISATION

- The OCEAN project has demonstrated electrochemical production of oxalic acid via two formic acid pathways from captured CO_2 (from RWE's Niederaussem power plant), H2 and glycerine (by-product from biodiesel production) at TRL 6. Coupling of oxidative and reductive electrosynthesis processes is fundamental to efficiency improvement while reducing costs, wastes and emissions. Demonstration as part of the project OCEAN at an industrial site has achieved this aim. Oxalic acid is synthesized in a three-step process from potassium formate which is electrochemically produced from CO_2 at the cathode whilst simultaneously producing glycerol by oxidation at the anode. By producing the same intermediate product at both electrodes, the faradaic efficiency can be increased theoretically by up to 200%.

DIRECT AIR CAPTURE

- The use of amino acid salts for DAC has been investigated by a team from CSIRO (Australia). Experimental assessments and mass transfer performance of these salts were evaluated to determine their robustness. In addition, various gas-liquid contacting devices were characterised for capture of CO_2 from the air. An amino acid salt (named as AAP1) was found to be a suitable candidate for DAC, due to its low volatility, high stability, and reasonably high CO_2 capture capacity and mass transfer rate. The results also indicated that simple standard cooling towers can provide an effective contact area for the reaction between ambient CO_2 and the absorption liquid. The thermodynamics and mass transfer data collected for the selected amine were used to develop a simple model and preliminary design for a demonstrator that is capable of capturing around 100 tonnes CO_2 a year. An overall capture cost of $67/tonne CO_2 is projected for air capture using the amino acid salt solutions investigated.

TRANSPORT & SHIPPING

- Japan CCS Co Ltd initiated a six year project in 2021 to design, build and demonstrate the ship transportation of CO_2 as a precursor to a much larger scale replication. To confirm the technical feasibility of this concept a demonstration ship with a capacity of approximately 1,000 tonnes of liquefied CO_2 will be operated for about 10 voyages per year. In addition, onshore facilities will include a shipping terminal used at the site of the Kansai Electric Power Co. power plant in Maizuru, on Japan's west coast; and a receiving terminal in the port of Tomakomai. The aim of the project is to demonstrate liquefied CO_2 ship transportation technology at a scale of 10,000 tonnes per year. Results will be used to develop business models for the purpose of CCUS. The demonstration ship, now under construction, will be a dual-purpose ship for transportation of liquefied CO_2/LPG. The specifications for a vessel with cargo tanks exceeding 60,000 m^3 has been determined and Approval in Principle (AiP) for the design has been obtained.
- One of the key objectives of this project is to test the management of technologies related to the ship transportation of liquefied CO_2, such as cargo control (temperature, pressure, oscillation), operational control (cargo handling, measurement, replacement of different liquids), and safe navigation (manoeuvrability and response to emergencies). The associated business model connects CO_2 ship transportation with a domestic CO_2 capture chain. It will: calculate and map the nationwide virtual CO_2 FOB (free on board) costs with a minimum CO_2 emission level; verify and establish multiple virtual CO_2 storage sites; and calculate transportation ship costs between CO_2 emission areas and storage sites for multiple ship types. Special attention will be paid to steel mills, which account for about 14% of Japan's CO_2 emissions.

PANEL DISCUSSION 1: ROUND TABLE ON POLITICAL ISSUES

The first panel of the GHGT-16 Conference focused on highly topical political issues related to CCUS. It was chaired by Florence Delprat-Jannaud – Chair of ClubCO_2 and Conference Co-Chair. The other panellists conveyed a broad spectrum of views from government, industry, research, a leading environmental organisation plus a CCS advocacy. These pre-eminent representatives included:

- Jarad Daniels - GCCSI
- Jennifer Wilcox – USDOE Office of Fossil Energy and Carbon Management
- Stéphane Tondo – ArcelorMittal
- Pierre-Franck Chevet – IFP Energies nouvelles
- Toby Lockwood – Clean Air Task Force (CATF).

The significant role governments play in CCS development was highlighted by Jennifer Wilcox who outlined the very considerable support for technology advancement. The $62B US Government's stimulation package includes $12B for carbon infrastructure. This includes $3.5B for four projects on natural gas power plants to integrate them with CCS. Another two industrial sites will also be supported plus $2.5B for storage and infrastructure. Jennifer stressed that this initiative is aimed at scale-up. Each storage site must have capacity for 50Mt/CO_2. She also highted the importance of first-of-a-kind (FOAK) projects to demonstrate the effectiveness of CCS, and to stimulate private sector investment, especially in regions less conversant with storage where there is less O&G, such as the Pacific north-west.

It is now clear that 1,000s of millions of tonnes of CO_2 need to be stored each year. To achieve this goal, transport infrastructure will need to be increased including the expansion of the 5,000 miles (8,047 km) of CO_2 pipeline to ~10,000 miles (16,093 km).

The recent Inflation Reduction Act (IRA) allows CO_2 capture projects to be capped at $85/t and DACC $185/t. The forward looking programme also includes deep saline formations, depleted oil and gas (O&G) fields plus mineralisation projects. MRV (monitoring, recording and verification) of nature-based solutions, such as soil-based sequestration, are to be evaluated to test whether they are robust and durable. A key issue is the verification of MRV so that CO_2 removal (CDR) methods are standardised to make sure they are consistent and robust.

Jarad Daniels stressed that one of the key roles for government is to set the regulatory landscape. This allows the development of large-scale durable and lasting CCS which is capital intensive. The approach should not just be confined to developed economies but extended to developing nations. Refinement of the 45Q tax credit, which has been in place since 2008, has provided valuable lessons for the forward programme. It is also evident that more subsurface data is required in many countries, which governments can help with, as well as capacity building.

Industrial R&D is gathering momentum, evident from biofuels and chemical recycling of plastics in France, which is a world leader in these fields. Pierre Franck Chevet, who is directly involved in these areas, also stressed that technology maturation depends on stable regulation.

One of the largest industrial sectors, steel, needs CCS. It produces ~7% of GHG emissions world-wide and, although there are new technologies such as DRI (direct reduced iron) using hydrogen, which could replace conventional blast furnaces, there will still be some process emissions. Stéphane Tondo also explained that steel is an iron/carbon alloy. Even with the use of electric arc furnaces CO_2 is released as a process emission from the degradation of the carbon electrodes, so the process is not completely carbon neutral. Stéphane then explained that there are wider dimensions to adopting new production methods. There are, for example, policy implications notably hydrogen supply. Certainty on its availability in the future is not clear and requires policy directive. A revised global investment policy does have global implications especially for renewable energy resources.

ArcelorMittal is an early-adopter and aims to decarbonise production by 2025-26. The steel market will change with different product methods like DRI and hydrogen use in other applications. Low carbon steel also needs to include carbon capture. However, the global market for such products is not harmonised so there is no level playing field. European policy has to ensure that cross-border trading of steel products from outside the continent must have the same standards. Exporting steel outside of Europe will become more expensive which could become a major challenge. ArcelorMittal have initiated a CO_2 capture demonstration in France and in Belgium. The CO_2 is to be reused for manufacturing e-fuels.

Toby Lockwood highlighted a key barrier to the development of CCS in Europe - the lack of developed storage. Northern Lights is the only storage project in Europe in construction. If no new sites are developed soon there will be a 50% short fall in storage sites by 2030. He advocated government led stimulus for transport and storage infrastructure development to meet future demand. Toby also mentioned that commercialisation of low carbon products requires demand-side drivers such as low-carbon support for products. There are, for example, no EU tax credits only ETS. There is the SDE++ mechanism in the Netherlands and contract for difference (CfD) mechanisms have also been proposed. Public procurement of low carbon products may help. By growing demand there should be better control over carbon content of products.

Societal acceptance of CCS was raised as a key issue but it will be dependent on community engagement. Jarad mentioned that data transparency from trusted sources can vary. He highlighted the positive initiatives done by the US Regional Carbon Sequestration Partnerships in this area. Jennifer Wilcox noted that this is a very hard topic because CCS is linked with fossil-fuels and methane emissions. Consequently, the opportunity "strings attached" support for projects must include: a community benefits plan (20%); justice benefits to disadvantaged communities (40%); and stakeholder engagement. Benefits from pollution reduction by retrofitting CO_2 capture also offers direct community benefits.

The theme of public acceptance was also commented on by Pierre Franck Chevet, explaining that trying to convey the benefits from the introduction of new technologies was a major challenge. He suggested that stakeholder engagement and inclusion should be included in committees involved in technology development.

The chair of the panel, Florence Delprat-Jannaud, asked fellow panellists how long CO_2 storage sites should be monitored for. Jarad replied that CO_2 storage is mandated as permanent, moreover, CO_2 will eventually go into solution. Secure storage also needs to be based on scientific data. In most US states monitoring will last 50 years with the exception of California where it must be monitored for 100 years and mitigation measures are necessary.

The panel expressed the view that there is a compelling case for CCS especially for hard to decarbonise sectors. With high energy prices, and need for energy security, there are good reasons to include CCS in the energy mix. Low-carbon products like steel initiatives are needed but should convergence on a defined standard which has an embedded environmental benefit across the EU, for example. Public procurement could help market development as well as large steel users like car manufacturers. This strategy can be used to help communicate the benefits of CCS to consumers. Ultimately carbon abatement measures may lead to a relatively low incremental additional cost to products.

Investment across a portfolio of CO_2 hubs will be essential but connection with known storage capacity is a bigger concern. There is also a clear requirement in life cycle assessments (LCAs) to improve carbon accounting methodologies. Governments can then use data to develop and implement incentives to decarbonise industrial sectors. Part of any forward policy also needs to include engagement with unions who represent a key constituent stakeholder group.

This highly stimulating discussion concluded with an overriding imperative – there must be trust in long-term policy initiatives.

PANEL DISCUSSION 2: ADVANCING INDUSTRIAL DECARBONIZATION IN DEVELOPING COUNTRIES USING CO_2 CAPTURE AND STORAGE

The topic for the 2nd discussion panel at GHGT-16 was entitled "Advancing Industrial Decarbonization to Developing Countries using CO_2 Capture and Storage". The lead panellist, and chair, was Tim Dixon, IEAGHG's General Manager. The international flavour was reflected in this panel:

- Dayo Adeshina – Nigeria, Office of the Vice President
- Rachael Moore - International Energy Agency (IEA)
- Rachmat Sule – Indonesia National Center of Excellence for CCS and CCUS at Institut Teknologi Bandung
- Seyi Adeyemo – International Finance Corporation (IFC)
- Brendan Beck – World Bank

Each panellist then briefly explained the development initiatives they were involved with.

Rachmat Sule explained that there is a CCUS centre of excellence in Indonesia. The ADB (Asian Development Bank) have supported 15 parallel studies on CO_2 reduction from industry within the country. There are no carbon credits yet but they are to be introduced in 2023. There is a contract mechanism for the use of CO_2 in the O&G sector. Under this scheme if the supply of CO_2 for EOR results in a negative income for the project the government receives less tax. If positive the operator gets more revenue.

The Nigerian policy was explained by Dayo Adeshina. In 2015 the Nigerian president announced a 20% emissions reduction policy to kick-start NDCs which were then submitted in 2017 and revised in 2021. This is the first energy transition initiative in Africa and it starts in the industrial sector. There has been a stakeholders' workshop on the legal and regulatory aspects plus a scoping plan for the cement sector.

Rachael Moore explained that from an IEA perspective CCS has a key role in moving from 45Mt/year in 2022 to 1Gt/yr by 2030. She also stressed that the technology was especially important for the hard to abate sectors and as a path for low carbon hydrogen production. Industrial CCUS is especially important in developing economies for sectors like cement that provide key materials for development such as wind energy, roads and other infrastructure. Steel also produces 10% process emissions even where low carbon routes are used.

Seyi Adeyemo mentioned a Climate Change Action Plan that includes CCUS in Nigeria. It will include emission sources and storage sites in country.

Finally, Brendan Beck explained that investment via governments in developing countries is possible via the 2009 CCS Trust Fund. The UK and Norway are its two donors. 10-15 countries have subsequently been identified for preliminary assessment of CCUS. A Phase 1 assessment has led to Phase 2 assessments in Mexico and South Africa including storage in basalt. Nigeria and Timor Leste are building capacity around CCS. This includes the Bayu-Undan storage project in the Timor Sea.

Tim Dixon then posed a series of questions which were directed to different panellists.

He asked Rachmat Sule what role does CCS play in Indonesia's transition. Rachmat replied that a significant challenge faced by the country is its heavy reliance on coal-fired power plants. Captured CO_2 from this source, and ammonia and natural gas production, could be used for CO_2-EOR as an initial step.

Dayo Adeshina was asked about the incentives offered by the Nigerian Government to implement CCS. In response Dayo explained that incentives include capacity building of regulatory authorities and awareness campaigns. The Office of the Vice President is leading the initiative and collaborating with the IEA and the World Bank.

Tim then asked how CCUS contributes to Nigeria's CO_2 reduction target. The country's O&G industry will develop CCS after successful completion of pilot projects. Cement and steel will get buy-in from established industry, although agriculture (fertilizer production) is not as organised as other sectors.

From the IEA's perspective, Rachael outlined the role of international organisations in CCS. She stressed the importance of the experience gained from the USA, Europe and Australia which leads to knowledge transfer. However, there must be partnerships with developing countries to ensure effective capacity building. The IEA will respond to member countries to identify ways for countries to decarbonise. In-country plans can be adapted with help. In Indonesia, for example, coal-fired power plants are relatively young so it would be prohibitively expensive to retire them now especially with energy security implications. Low-cost activities are encouraged to kick-start the foundation of CCS. The IEA needs to have confidence in storage as it is the key to attracting investment in CCS. Regulations and a framework based on experience elsewhere is very helpful. In answer to the roll of the private sector in developing countries Seyi Adeyemo mentioned the importance of pilot CCS projects. Although there are very few, they are helpful. Seyi then went on to express the view that the private sector needs to promote solutions and engage in developing countries. A good starting point would be to start thinking about hubs and collaboration. The IFC are looking to invest in upstream work on pre-investment activities.

Tim asked Brendan how the views of the World Bank have changed since the Trust Fund was set up in 2009. In reply Brendan said that interest in CCS is growing and essential for climate change. The World Bank development reports on climate mitigation goals. Therefore, the presence of cement and steel in countries like Turkey and Vietnam cannot be ignored. Uzbekistan, for example, has a gas-based economy and therefore has an interest in "blue" hydrogen.

Brendan was then asked how the World Bank will continue activities post Trust Fund (which runs out in December 2023) as there is a need for support in countries with CCS potential. Brendan alluded to an Industrial Decarbonisation Fund that is now available. The Green Climate Fund could also fund CCUS assessment in developing countries.

Another factor to take into consideration are NDCs in developing countries. They are needed but governments have competing and often greater priorities. There can be beneficial opportunities where CCS could help with economic development and environmental benefits from CO_2 abatement. Decarbonising natural gas from LNG production, for example, is a key opportunity. The Timor Leste Bayu-Undan depleted gas field could be a CO_2 storage site and provide a revenue stream for the country.

The panel concluded with an optimistic note. There is a lot of activity in emerging nations like Indonesia and Nigeria where CCS is beginning to attract more interest and move forward from early pilot projects to larger scale storage and capture from multiple industrial sources. Greater interaction from countries with experience in CCS and developing economies is essential and needs to be facilitated.

PANEL DISCUSSION 3: CO_2 IMPURITIES FOR MULTIPLE SOURCE NETWORKS AND HUBS

The 3rd Panel discussion (panellists pictured below) entitled 'CO_2 Impurities for Multiple Source Networks and Hubs' took place on 25th October 2022. The Panel was chaired by Haroun Mahgerefteh, University College London. The panellists, affiliations and their areas of interest were as follows:

- Richard Porter – University College London: Opportunities and challenges of achieving European CO_2 transport specifications
- Simon Roussanaly – SINTEF: Impact of impurities in tanked-based transport of CO_2
- Heike Rutters – Bundesanstalt fur Geowissenschaften und Rohstoffe (BRG): Impacts of impurities on the storage infrastructure /site
- Filip Neele – TNO: Techno-economic trade-offs for CO_2 impurities in CCUS chain integration.

CCUS cluster networks is a novel way to advance industrial decarbonization. However, multiple CO_2 emissions from industries such as the iron and steel, cement, chemical and refining, in addition to those of the power sector, will bring together gaseous streams with different CO_2 concentrations and various impurities that will make them differ in their physical and chemical properties. Impurities in the CO_2 stream have the potential to affect the efficiency and safety of transport system and storage solutions. Accurate monitoring of CO_2 stream composition and metering in a transport network will therefore be critical for optimised safe and robust operation. The panel discussion gave an update of CO_2 stream impurities issues for operators, regulators, and researchers, based on the experience of various pilot and industrial scale CCUS projects.

Richard Porter in his panel presentation sought to answer the big question: what is the optimum range and concentration of impurities that can be tolerated in the CO_2 stream to enable its safe transport and storage at minimum cost? He stressed that there are significant differences in the CO_2 storage specifications depending on the project. Pipeline transport and storage of CO_2 with relatively high concentrations of some impurities are technically feasible (e.g., CO, H_2S) as demonstrated by the North American EOR experience. Linked to this there is a need to perform whole chain integration techno-economic analysis and optimisation (i.e., cost of purification vs cost of using more corrosion resistant material).

Simon Roussanaly summarised CO_2 impurities in the context of ship transport. He presented the CO_2 specifications for the delivery to the Northern Lights infrastructure. The Northern Lights CO_2 stream specification has raised questions, especially from CO_2 source and capture side.

These specifications might be too stringent and may likely increase the cost of CO_2 capture and conditioning significantly. The specification for water, for instance is ≤ 30 ppm and oxygen ≤ 10 ppm.

For different industries to agree on an optimal specification or range is challenging because:

- Impurities are industry, CO_2 capture technology and even case-specific
- It depends on the elements considered in the chain
- Impurity removal cost depends on the type of impurities, levels, and specifications
- Many technical aspects matter (corrosion, energy, safety during abnormal operation, etc., along the whole chain)
- Potential synergy effects between impurities bring further complexity.

Simon Roussanaly concluded that there may be room to relax the current specifications for shipping of CO_2 and this may depend on the final shipping pressure selected. It might be wise to focus on impurities that have a strong cost reduction potential.

Heike Rutters presented on CO_2 stream composition in storage reservoirs and focussed on two discussion points:

- Composition of CO_2 stream for injection
- Behaviour and fate of impurities in storage reservoirs.

This interactive session further raised questions during the panel discussion as to what are the compositions of the CO_2 streams actually transported and how much variability of CO_2 stream composition is acceptable. Filip Neele pointed out that interoperability is a key issue and compositions used by early projects should not be too strict (or, open for future definition). Secondly, composition variations have an impact on conditions in transport and storage systems. Therefore, this factor should be taken into account in transport and storage network management. Changes in phase behaviour should be included in storage site monitoring as well.

In a nutshell, this panel discussion has reaffirmed the significance of the broad spectrum of pollutants in CO_2 streams that could converge in CCUS clusters emanating from different industrial processes. The issue poses a huge challenge to the management and standardisation of CO_2 stream specifications for transport and storage. This aspect underscores the critical need for industries to work in tandem and come up with practical solutions to address the variations in the specifications of CO_2 streams (emanating from different industrial projects) for transport (via ships and pipelines) and geological storage.

PANEL DISCUSSION 4: THE CHALLENGE TO THE CCS COMMUNITY POSED BY UPSTREAM EMISSION SOURCES I.E. METHANE

This panel session was jointly moderated by Sean McCoy (University of Calgary) and Susan Hovorka (University of Texas). The panellists included Gaelle Cauchois (Carbon Limits), Rachael Moore (IEA), Jose Benitez (USDOE), and Jon Gibbins (University of Sheffield). This panel used a very interactive format, posing questions to the attendees, which were then used as starting points for further elaboration by the panellists.

Some attendees were probably surprised to learn that, assuming a 1% CH_4 (methane) leakage rate, a pulverized coal power plant equipped with CCS (PC-CCS) has lower LCA carbon emissions than a natural gas combined cycle plant with CCS (NGCC-CCS). There is a lot of variability and uncertainty in the CH_4 emissions estimates though, especially for the upstream emissions parts, and the resolution of the collected data is quite course currently.

The CH_4 leakage rate for oil and gas productions in the Permian Basin can be anywhere between 2-6%. This range is due to the different technologies used for production/extraction and measurement of the emissions. It is also often not clear how much of the leaked CH_4 is attributed to oil or to gas production. Another issue to keep in mind is the dynamics of emission factors, for example over time, as the age of infrastructure increases, so will the amount of leaks.

Next, there was a discussion of 'blue H_2 (hydrogen) versus NG (natural gas) with CCS /DACCS'. It is unclear yet, which pathway will be more cost effective and sustainable, especially after infrastructure investments required for a change from NG to H_2 are taken into account.

Panellists agreed that using either a correct GWP20 (global warming potential) or a GWP100 approach are selected (both could be used) will depend on the context and the research questions asked.

Currently, about 15% of global energy sector emissions are from indirect upstream emissions, which is equivalent to a loss of 180 bn m^3, and CH_4 emissions in the energy sector rebounded in 2021. Russia and the USA emit the most in total terms but they are also the main producers, so the emissions intensity is actually relative low. Norway has the lowest emissions intensity, due to very strict regulations. It was also pointed out that implementing tried and tested policies could easily halve CH_4 emissions. This all means that even NGCC-CCS with 99% CO_2 capture rate can overall only be as good as the amount upstream emissions.

What can be done now in absence of better data collection and measurement is to reduce venting and fix leaks in a timely manner. This is usually low cost, for example, addressing emissions related to bleed valves comes at about \$10/tCO_2.

The session concluded with the following key messages:

- Choices cannot be made purely on economics
- There is a need to identify the appropriate tools to answer the specific research questions
- There is a need for a portfolio, not a single option, and a holistic systems point-of-view
- Both CO_2 and CH_4 abatement are required. If the process involves NG, then CO_2 mitigation alone is not enough
- Following from the previous point, there is a need to get to net zero greenhouse gas (GHG) emissions and there is a need to clarify what the implications are for this.

PANEL DISCUSSION 5: COMMERCIALISING CCUS IN THE MIDDLE EAST: GULF REGION AND EGYPTIAN HUB STUDY CASES

This panel discussion was held on Wednesday 26th October 2022 and saw moderator Rachael Moore from the IEA welcome three speakers to discuss the potential for CCUS in the Middle Eastern countries and Egypt. Iain MacDonald (Shell), Al Collins (Oxy) and Tidjani Niass (Saudi Aramco) provided insights on recent action from the OGCI (the Oil and Gas Climate Initiative) and GCC (Gulf Cooperation Council) and relevant perspectives on the commercialisation of CCUS.

The OGCI is aiming to lower carbon emissions via collective action and partnerships, with a strategy refresh undertaken in September 2021, that focusses on three main pillars: net zero operations and leverage influence; leading the oil and gas industry; and acting to help decarbonise society. Efforts are being made in this initiative to kickstart the CCUS industry through hubs. Initial efforts have recognised that hubs were mainly European and North American orientated in 2019, leading to the question of what the barriers or challenges were in other parts of the world. The OGCI Global Hub Search highlights 279 potential hub opportunities in 56 countries, matching clusters of CO_2 sources with potential geologic storage locations.

This modelling effort was a qualitative assessment considering the various factors which will influence hub location, including policy / regulatory support, carbon pricing, emission targets, existing CCUS commitments or activity, local value chain expertise, and political stability. The OGCI CO_2 Storage Resource Catalogue is another important activity as it is the first independent assessment of global geologic storage evaluation. This assessment is complemented with other relevant activities including work on Article 6 and Carbon Storage Units, a review of policy mechanisms in 2018 and involvement in ISO Technical Committee 265 which focusses on CCS.

OGCI appreciate that to achieve their three pillars, collaboration is key – it's bigger than just 'oil and gas'. Knowledge sharing and working together is of utmost importance. The storage catalogue and hubs playbook take public information and presents it to stakeholders in a pre-competitive state. To help facilitate this collaboration and knowledge sharing public references from organisations such as IEAGHG, the IEA and GCCSI are used. There are some limitations of the work, for example the hub search results may not necessarily reflect all data because a lot of companies / countries don't publish full reservoir data publicly, reiterating that more work is needed in such areas. OCGI are particularly interested in gaining more data from South-East Asia, India, Egypt, Brazil and Mexico to assist with delivering roadmaps and a narrative on the value of CCUS in those countries.

The Gulf Cooperation Council (GCC) is a group consisting of six countries (Saudi Arabia, UAE, Bahrain, Kuwait, Oman and Qatar) with a huge energy abundance (both in oil and gas and the potential for solar and wind), but with scarce water resources in a harsh environment, and alongside carbon intensive industries. There are significant opportunities for CCUS in the GCC that would span both climate and socio-economic benefits, by capturing new markets and enabling a least cost net zero future in the region. Currently, there are four large-scale CCUS facilities in the GCC region capturing 4.2 M tonnes per year. There are abundant sources of CO_2 already concentrated in clusters in the region with approximately 170 Gt of storage potential in saline aquifers and oil and gas fields, although further work is needed to translate this potential into real opportunities. Saudi Arabia, UAE and Qatar are already advanced in their plans for CCUS hubs and the GCC is well positioned to become a leader in hydrogen. DACC could also help to enable carbon removal and e-fuel production. Oxy too has big DACC ambitions of at least 70 MT by 2035. All the panellists agreed that CCS and DACC will be needed, with the IEA recent DACC report being a good source of cost data on the technology.

Egypt is another country of potential commercial growth in CCUS. Their new climate strategy does mention CCS and four of the five main areas in this strategy demonstrate the value added of CCUS for Egypt. The country would benefit from sustainable economic growth, enhanced governance, enhanced financial structures and enhanced R&D knowledge transfer. OGCI have carried out a case study on Egypt on the potential for a low-cost hub in the region. It looked at storage resources and two possible hub models. Egypt has potentially vast geological storage resources: in depleted fields with the ability to store an estimated <2.5 to ~111 Mt CO_2; and in saline aquifers likely 3 to ~488 Gt CO_2. This estimated range is large because more work is needed to characterise the potential storage resources especially on understanding saline aquifers in the region and the specifications for CO_2 storage. OGCI considered two hub models in this study: a large-scale national hub and local industrial cluster hubs. The integrated costs of the national hub are approximately US $85 /tCO$_2$ and the individual integrated local hubs cost at around US $53-150 /tCO$_2$. The proposed infrastructure could lead to a significant ~100 Mt CO_2 reduction towards the country's NDCs. These hubs could also support DACCS and a future low-carbon hydrogen economy. Currently, CCUS is not commercially viable in Egypt but in the longer term, Article 6 and the Green Climate Fund frameworks could assist with the adaptation of the technology in the country. International and domestic opportunities need to be investigated further. Once there is a better understanding on the real storage resources, targets can be identified and investment becomes more viable. This case study, and hub modelling work, will be published by the OGCI in late 2022 or early 2023.

It is surely a positive sign that Egypt has CCUS included in their first NDC (INDC) and other countries should followed suit if they haven't already. Inclusion in the NDCs will allow for more financing and support. Another issue of importance (worldwide, not just for Middle Eastern commercialisation opportunities) is the approach taken to account for contributions from negative emissions. It will be crucial for countries and companies to ensure that there is no double counting especially carbon credits accrued from CCS. The is a hugely important issue and more effort is required to develop accounting methodologies, coupled with best practice procedures, to ensure that issues such as double counting are properly mitigated and prevented.

In conclusion, the panellists emphasised that we should try and get away from the narrative that CCUS is a silver bullet and let countries know that it is an opportunity – it is not a cost, it is not a problem, and it can be done.

PANEL DISCUSSION 6: REPURPOSING EXISTING INFRASTRUCTURE

This final panel discussion took place on Wednesday 26th October 2022. The moderator and chair, John Lityinski of US DOE FECM, welcomed four panellists in a discussion on the repurposing of existing infrastructure. Tony Espie (BP), Bente-Helen Leinum (DNV), William Van Geertruyden (ExxonMobil) and Sarah Leung (US DOE) provided insights and perspectives from their experience. They started with an overview, then answered three questions posed by the chair, and wrapped up with an open question session from the audience.

Tony Espie has worked on repurposing and requalifying assets since the mid 1990s and kicked off the discussion, stating that the idea of repurposing has broad appeal, but what are the main issues to contend with as assets are assessed? These include infrastructure such as pipelines, platforms and wells, and data. There are a range of rich datasets and operating history that is not always easy to get hold of but can provide evidence that there is a suitable seal and reservoir. There is upside potential for additional revenue streams with incremental recovery and deferred abandonment costs.

He fleshed out some issues that were critical to assess: potential leak paths (exploration, appraisal, production, and injection wells); geo-mechanical history (depressurisation and repressurisation); potential for Joule-Thompson cooling (where CO_2 is transported at high pressure in the dense phase and injected into a low pressure reservoir and has implications for well integrity); and liability management, particularly when there is a change of operator.

What are the key priorities to ensure the potential for re-use? Thinking and planning for transition earlier rather than later seems to be the main message. For example, prior to well abandonment and the timing and status of field depletion. Maintenance regimes for facilities, wells and pipelines are critical as are data management and preservation.

Bente-Helen Leinum has a wealth of experience with pipelines and emphasised the value of industry standards and guidelines when building new and reusing existing pipelines. The industry has a long history in designing pipeline on and offshore and assessing integrity if the fluid has changed.

There are already a set of design standards in place with DNV (2010) and ISO (2016) standards. The requalification process should comply with same requirements as those for designed pipelines especially for the transportation of CO_2. DNV have published a recommended practice document for the design and operation of CO_2 pipelines. Robust guidance on the safe management of pipeline infrastructure can establish trust and confidence between stakeholders, authorities and society.

However, one of the limitations can be access to the original specification documents. The existing rules state documents must be kept for 10 years. For a 30 year old pipeline these documents may not be retained which makes repurposing less straightforward.

Another key consideration is the phase of CO_2 transported. CO_2 in the gas phase is more similar to natural gas than the dense phase, this may be critical if there is a maximum operating pressure for an existing pipeline. There is a drawback because in a gas phase there is a lower transfer capacity. Other factors also need to be considered when repurposing a pipeline to transport dense phase CO_2 such as corrosivity, temperature, dry ice formation and the capacity to withstand running fractures.

William Van Geertruyden summarised ExxonMobil's proven track record in CCS, with over 30 years developing and deploying CCS technologies at scale. ExxonMobil have a large stake in global capture projects and have captured ~40% of the anthropogenic CO_2. Low Carbon Solutions is a new business line (2021) which incorporates CCS as a critical part. One such project is the LaBarge, Wyoming CCS facility which has a current capacity of 7Mt CO_2/yr.

In order to consider repurposing infrastructure for transport and storage William advocated a full system risk-based approach. Current materials are designed for pressures and temperatures appropriate for hydrocarbons. Echoing Bente-Helen's comments CO_2 is a different medium to be transported and stored. CO_2 composition and impurity limits will also be critical. Carbon steel will be the most likely basis for the majority of future infrastructure needs in transport and storage. Codes and standards will need to be developed, or updated, to accommodate new opportunities. Innovation in technology and business models will be key to overcoming those challenges.

Sarah Leung emphasised the tyranny of distance "as we seek to connect the storage and sinks, we need to be thinking about the assets we have today and the build out of new infrastructure, so we don't have stranded assets". She presented the milestones necessary to achieve the US decarbonisation goals starting today through to 2050. Modelling results of CO_2pipeline requirements shows that the 5,300 miles (~8,532 km) of pipeline in existence today needs to extend to 11,000 miles (~17,707 km) by 2030 and by over 25,000 miles (~40,244 km) by 2050.

In February 2022 US DOE FECM ran a workshop to connect industry, professional associations and other governmental stakeholders to talk about technical R&D, policy and regulatory challenges in repurposing pipelines and wells for carbon transport and storage. Objectives included exploring technical advancements, operational considerations, RDD&D gaps, and regulatory considerations. The outcome was a published report (available on request) which included recommendations to identify the research and funding needs.

Sarah provided an update on the status of US regulations. The Bureau of Ocean Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE) are currently updating offshore regulations for the geological sequestration of CO_2 on the Outer Continental Shelf as directed by the Bipartisan Infrastructure Law. The EPA's guidelines on the transition of Class II wells to Class VI wells is well established, and is being appropriated. The US DOE is also working with the Department of Transport Pipeline and Hazardous Materials Safety Administration (DOT PHMSA) who are initiating new rules to update standards for CO_2 pipelines.

Other DOT entities include rail (Federal Railroad Administration) as CO_2 is already transported by rail and the Maritime Administration (MARAD) as CCS moves offshore. The US Coast Guard, which looks after port security, has also been consulted as there will be a need to transfer CO_2 from onshore to ships.

Lastly, Sarah reviewed the current funding opportunities supporting repurposing infrastructure, including elements within the Bipartisan Infrastructure Act and Inflation Reduction Act.

The chair then posed a series of questions to the panellists:

1. Comment on CO_2 specification requirements for existing (H_2S and other impurities) purification requirements that might affect the economics of a project? What benefits are there to setting standards that broaden the access for other users of infrastructure and storage facility?

One of the key challenges in dealing with impurities is phase behaviour and thus flow behaviour. These properties change with impurities which can cause corrosion of the steel. For example, in the case of Northern Lights CO_2 will be transported from a variety of sources which has implications for impurities. This issue will also be true also of hubs. Consequently, there is a requirement to extend the specification and guidelines. Research in this area has been conducted by IFE (Institute for Energy Technology) for the past 30 years.

Wells are corrosion resistant so can probably handle the presence of impurities, however, understanding the impact on surface facilities will be critical. There are also issues caused by cooling within the wellbore that can lead to the potential for slugging and hydrate formation.

There are some legal constraints about what can be stored offshore. The London Convention states what can be stored. Previous concerns with the convention have been raised. If the CO_2 was permitted it might open the door to the disposal of more toxic material especially if co-disposal took place. The London Convention includes the term 'overwhelmingly CO_2' which is intended to acknowledge 100% CO_2 may not be possible. DOT PHMSA allow a concentration of CO_2 90% or greater.

2. A significant amount of data on the existing fields and their performance during production exists. How can this be leveraged and what data may be needed as the field production is transformed to injection operations?

Bente-Helen noted that for requalification you must have design criteria. The business case needs to fit with the pipeline. In terms of general documentation, most companies have good records but if there is a change of operator data may get lost in the process.

Tony Espie stressed that subsurface data becomes important. He pointed out that it is not always easy to predict dynamic systems and real performance usually has surprises. A range of boundary conditions exist, that become ultra-important. Most people think of a constant stream of CO_2, but hubs will have fluctuations in rates and compositions.

3. There are a number of opportunities to develop storage resources adjacent, below or above producing oil and gas assets. What technical and legal challenges does this pose for project developers? Tony Espie raised the point that there are a number of issues on how storage will interact. Large formation with closures may be connected by an aquifer. If CO_2 is injected the pressure will propagate. If another entity wants to use an adjacent structure, it might have an impact on injectivity? No one knows how to address this.

Sarah answered that this question was part of the discussion in the February workshop. One of the unique challenges in the US is pore space ownership. This was discussed on a state-by-state basis. Timing of repurposing also matters, for example, natural gas pipelines in use today are not available for re-purposing. It is possible, however, that the same right of way could be used.

Questions arising from the floor included: a discussion on the criteria needed for pipelines transporting hydrogen; right-of-ways; impurities and the trade-off of removing impurities verses designing infrastructure to cope with impurities; community engagement and the re-use of wells.

To conclude it was recognised that more experimental data is needed to cover gaps in knowledge of the composition of CO_2 and the impacts. Time is now of the essence, each project is unique, there are lots of opportunities, codes and regulations that need to kept up-to-date so there is broad alignment.

The panelists from Panel Discussion 6 at GHGT-16.

In their concluding remarks and acknowledgements, Tim Dixon and Prof. Kelly Thambimuthu of IEAGHG, highlighted the breadth of the conference's content which had covered the whole spectrum for CCUS from initial scientific ideas to large-scale projects and now extending to full-scale full-chain deployment. This GHGT conference has again acted as the main global gathering of CCUS interests.

THE NEXT GHGT

The next GHGT was announced as **GHGT-17 – Calgary 20-24 October 2024 – Hosted by ERA (Emissions Reduction Alberta)**.

ERA is proud to be the host of the GHGT-17 Conference. The organisation plays a critical role in Alberta's climate action plan. Since 2009, ERA have committed $809 million (£471 million) toward 220 GHG emissions reduction projects worth $6.5 billion (£3.8 billion). This includes investing $122 million (£71 million) in CCUS projects specifically.

Calgary offers a unique conference destination, and the ERA team are committed to making GHGT-17 the biggest event in the series as well as a net zero event. The conference will take place in the TELUS Convention Centre in the heart of Calgary, Canada's 4th largest city.


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