Evaluating technology options to mitigate greenhouse gas emissions

annualreview 2022

IEA GREENHOUSE GAS R&D PROGRAMME

International Energy Agency

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Further information on the IEA Greenhouse Gas R&D Programmes activities can be found at:
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Document designed by Tom Billcliff.

Inside Cover Image: Construction works at the onshore Northern Lights facilities, Norway. Image courtesy of TotalEnergies.
Front and Back Cover Images: Palais de la Bourae, opening venue for GHGT-16, Lyon, France; IEAGHG ExCo Committee members at Exco61 in Calgiari, Sardinia; Badges for GHGT-16, Lyon, France; La Sucriere, venue for GHGT-16 conference dinner, Lyon, France; Exhibition hall at GHGT-16 Lyon, France; IEAGHG 30th Anniversary celebartion dinner, Lyon, France.

Annual Review Contents

IEAGHG ExCo members enjoyed a site visit to Saras' refining and power generation facilities located at Sarroch, near Cagliari, in May 2022.

Chairman's Message

As the world recovered from the economic hit of COVID restrictions, it was disappointing to see CO_2 emissions rise again, and the atmospheric levels reached 419 ppm by the end of the year.

The IPCC released the second and third of their three reports from AR6. Their third report covers mitigation of climate change, and it reinforced the urgent need for all mitigation options, including CCS, and why CCS is needed for permanent CO_2 removal (CDR). It is clear, in all scenarios we need gigatonnes of permanent CO_2 removals. It also highlights the significant risk to existing fossil fuel related energy infrastructure and other investments if we are to achieve limiting warming to 1.5°C or 2°C , in that the 'stranded assets' would be in the scale of trillions of dollars, noting that CCS would significantly reduce both GHG emissions and this financial risk.

Another significant report in 2022 was from our colleagues in the International Energy Agency (IEA), "World Energy Outlook 2022". Across both the power sector and the industry sector, the IEA points out that CCUS is an essential component of the portfolio of clean energy technologies and a direct beneficiary of the increase in clean energy investments across the globe. However, it also notes that "*A rapid acceleration in the deployment of carbon capture, utilisation and storage is needed in the NZE Scenario to deliver deep emissions reductions across the industry, power and fuel transformation sectors and to remove* CO_2 *from the atmosphere through direct air capture (DAC) and bioenergy equipped with CCUS (BECCS)*".

For IEAGHG, we were very pleased to get back to holding our major conference, GHGT-16, in-person in Lyon, France. The attendance exceeded expectations, as did the energy and enthusiasm of delegates for CCS development and deployment accelerating in many places around the world.

Kelly Thambimuthu at GHGT-16, Lyon, France

Whilst in Lyon, we also took the opportunity to celebrate in person with our many friends and supporters, past and present, our 30th Anniversary milestone which we reached in November 2021. Although delayed by pandemic isolation, it was an event undeterred in spirit celebrating our very many achievements, as well as in looking forward to many more years contributing to the deployment of CCUS to address climate change.

We look forward to seeing our international colleagues again in-person in 2023, whilst keeping safe and well.

K. V. Thambimuthu.

Kelly Thambimuthu,
Chairman of the IEAGHG Executive Committee

General Manager's Summary

I am very pleased to say that IEAGHG continued to work well under the COVID restrictions, which started to lift in the first half of the year, and our output remained high throughout.

Which is important because CO_2 emissions continued to rise above pre-pandemic levels, climate change continued, and CCS developments accelerated around the world.

The role of CCS and our work as IEAGHG was reinforced by the messages from the IPCC WGIII report on Mitigation, where we were pleased to see our nearly 100 substantive comments as expert reviewers to earlier drafts had been acted upon, and IEAGHG reports and papers cited.

Following the success of COP26 in Glasgow, it was good that COP27 was also able to take place in-person, at Sharm-El Sheikh in Egypt, although the high level outcomes could have been more ambitious. Whilst only a few Nationally Determined Contributions were updated, the Paris Agreement also calls for countries to submit long-term greenhouse gas strategies looking to mid-century, and many more of these were submitted and most of these have CCS included. So we have a lot of work to do to help these countries realise their CCS potential.

Tim Dixon at GHGT-16, Lyon.

A continuing theme at this COP was direct carbon dioxide removal (CDR) and many side events discussing various aspects of these suite of techniques and technologies. Our recent work on engineered CDR continued to be very relevant and needed. For IEAGHG it was also a successful COP, organising two side-events (one official UNFCCC) with our partners, and speaking at several others. We also input to the negotiations on Paris Agreement's Article 6.4, the new activity-based mechanism which will create internationally tradable credits.

Tim Dixon,
IEAGHG General Manager

To our membership, we were very pleased to welcome our new members Eni and Drax, and interest from many others. Our in-person meetings resumed, with careful Covid-risk management practices. Firstly our ExCo61 in Sardinia, then most significantly for us was delivering GHGT-16 in a fully in-person format with our hosts ClubCO_2 in Lyon, France. It exceeded expectations, with 1,200 attendees from 58 countries and around 700 presentations. The energy and enthusiasm was tangible, clear evidence that CCS deployment and development is accelerating. The in-person nature meant that we saw new ideas and new collaborations and initiatives arising as a result of GHGT-16.

We were also able to resume our International CCS Summer School in-person, in Bandung, Indonesia, hosted by ITB. As we ended the year, we have already started working on our meetings for 2023, such as the High Temperature Solid Looping Network, the Costs Network, the Risk Network, the Monitoring Network, and the Post-combustion Capture Conference (PCCC-7) which will be held in September in Pittsburgh. We have also already started working with our Canadian hosts, Emissions Reduction Alberta, in organising GHGT-17, to be held in Calgary in October 2024. We very much look forward to seeing many of you at the many meetings through 2023, both in-person and virtually.

Key IEAGHG Achievements in 2022

IEAGHG 2022

1200 total attendees at GHGT-16

11 technical reports

5 technical reviews

138 attendees at IEAGHG Risk Management Network - Webinar & Virtual Discussion: The Road to CCS Project Permitting

9 webinars

47 blogs

15 presentations by IEAGHG staff

14 information papers

115,128 website page views

60,784 sessions

1,406 YouTube views

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IEAGHG Operations Report

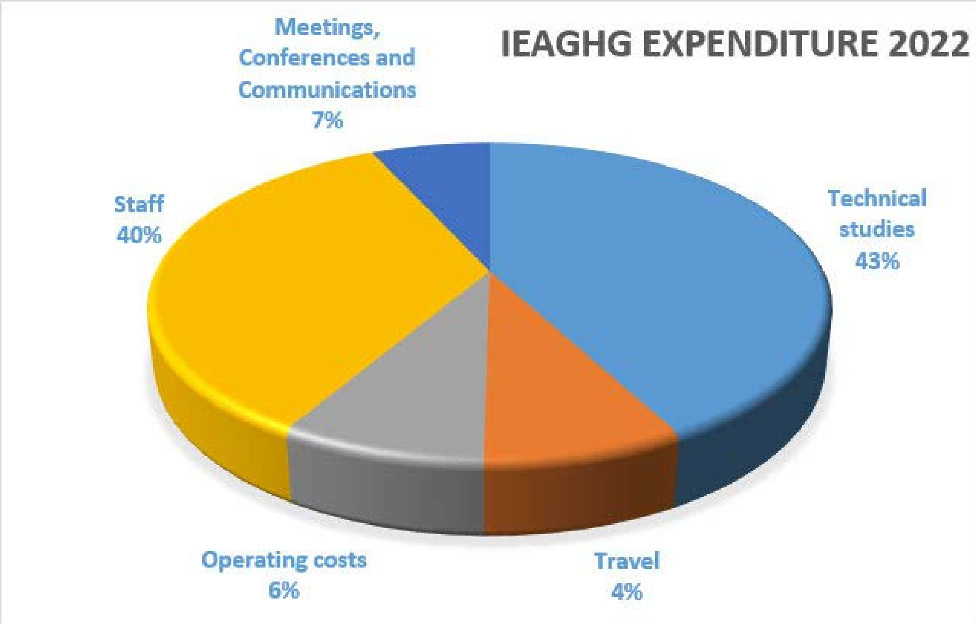
Membership grew to 37 members.

We welcomed Eni and Drax joining, and progressed many enquiries from other organisations as global interest in CCS development and deployment continues to grow.

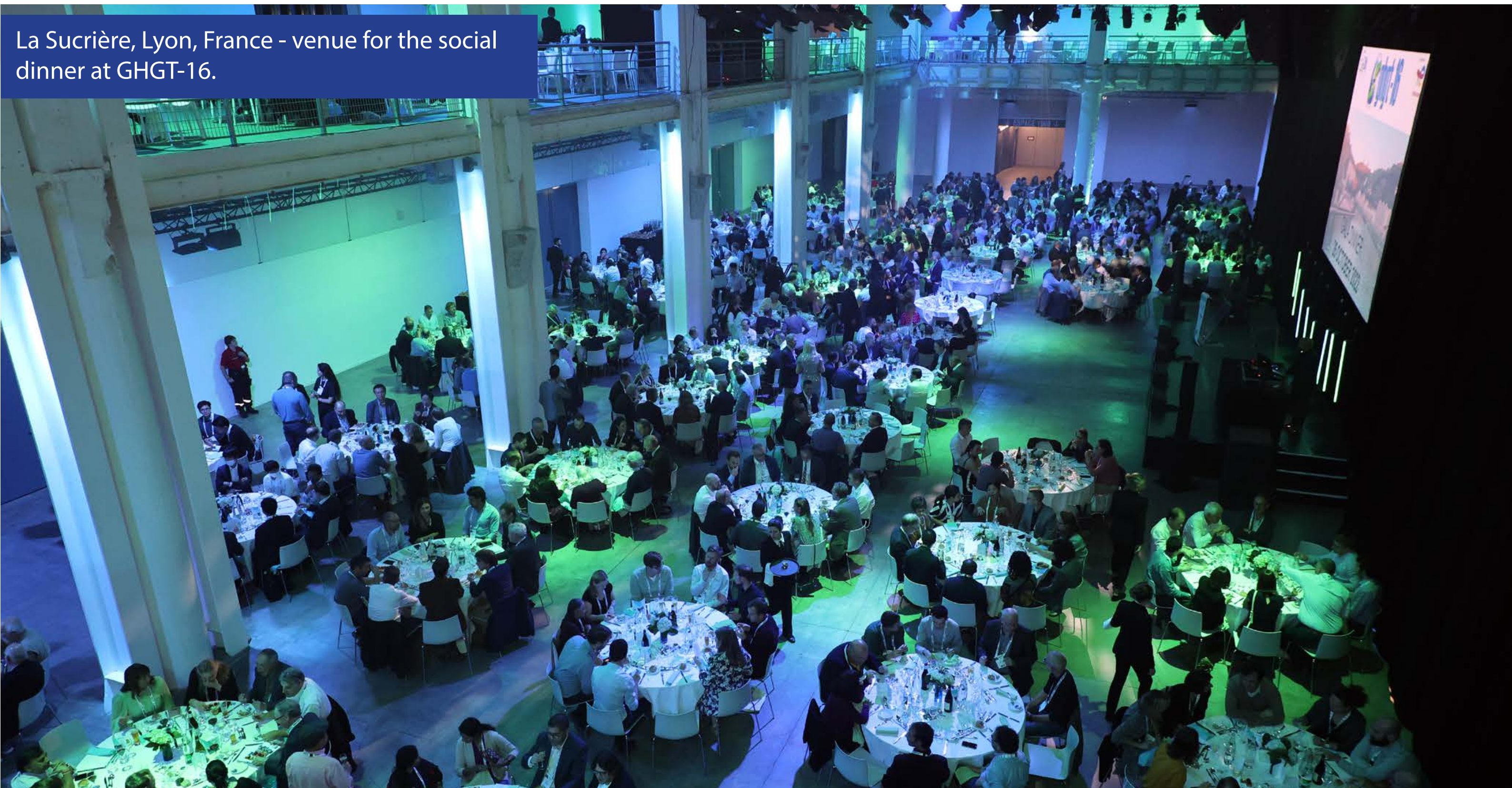
Our total annual income was approximately £1.7m, and the budget was allocated as illustrated below.

The Executive Committee, which is comprised of our member representatives and acts as the governing body overseeing IEAGHG's activities, met twice in the year. Because of COVID restrictions lifting, both meetings were held in-person. ExCo61 was hosted by our member Sotacarbo in Cagliari, and ExCo62 was hosted by France in Lyon in association with our GHGT-16 conference. Relevant site visits were provided with both.

We welcomed Dr Nicola Clarke to the IEAGHG team as Senior Technology Analyst leading on storage, and said thank you to Dr James Craig on his retirement at the end of the year.



Note 1: This spans over two financial years so values given here are approximated. Audited accounts are available to members.



La Sucrière, Lyon, France - venue for the social dinner at GHGT-16.

Facilitating Implementation

IEAGHG helps to facilitate the implementation and deployment of CCS by contributing the technical evidence-base to policy-makers, regulators and other decision-makers.

IEAGHG participates in key activities to support CCS policy/implementation strategies and by undertaking studies and workshops to provide information that is needed to assist CCS deployment.

UNFCCC COP27

Sharm El-Sheikh Implementation Plan

This was meant to be themed as the 'Implementation' COP, following the Glasgow 'ambition' COP and the Paris 'Agreements' COP. However this COP was also being called the 'African COP', and it is certainly achieving that, through the attendance by many from this continent, and the many exhibits, booths and events relating to Africa. IEAGHG did our part, with our UNFCCC Side-event on CCS in Africa.

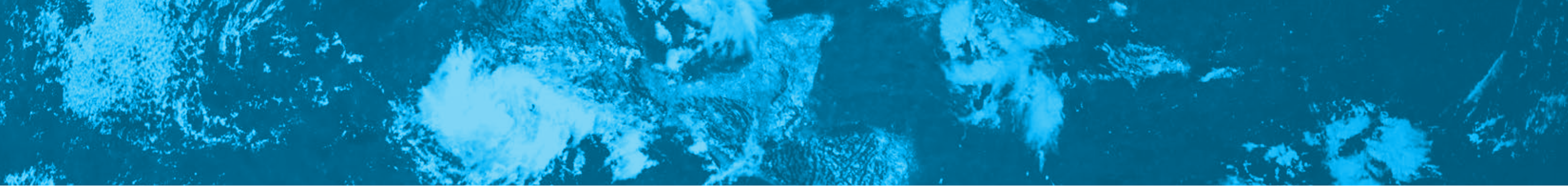
The cover decision, called the "Sharm El-Sheikh Implementation Plan" repeats Glasgow's agreements on aiming to keep 1.5 °C within reach, and that in itself was considered an achievement. The one significant achievement was to establish the principle of a fund for "loss and damage", for developed countries to fund the poorer developing countries for the damages from climate change, although no funding has been agreed. The energy section of the cover decision calls for an "increase in low-emission and renewable energy " which is understood to mean to include gas with CCS and nuclear.

Article 6

Within the many different negotiations the main area we have been following has been Paris Agreement Article 6.4, the new mechanism for international cooperation and carbon credits, and how it treats "removals", particularly engineered removals which are based on CCS ie DACCS and BECCS. Article 6.4 will enable a new international carbon market for project-based activities, like a new Clean Development Mechanism. IEAGHG's role to ensure decisions are evidence-based and there is no bias against geological storage based mitigation methods such as CCS and DACCS. Here, like the cover decision, the main achievement in COP27 from a CCS perspective was to avoid it going backwards. We were able ensure there was no bias in the final version of the text and it was hence technology neutral. Pre-COP27 documents from the 6.4 Supervisory Body had explicitly recognised the different requirements for accounting between nature-based and engineering-based removals, which used our inputs on the past work and agreements under UNFCCC and under IPCC for CO_2 geological storage. In the final text agreed in the Paris Agreement plenary (CMA) this area of removals has been pushed back to the SBSTA to do some more work and report back to CMA in COP27. This topic requires constant vigilance, and we will keep following this topic and inputting as necessary.

IEAGHG at COP27

Our primary activity was to be co-organiser of the main official UNFCCC Side-event on CCS, with the University of Texas, CCSA, International CCS Knowledge Centre, and Bellona. This was on CCS in Africa, with presentations on CCS activities in South Africa, Nigeria and Morroco, and a welcome from Brad Crabtree, Assistant Secretary, USDOE. This got good coverage by the COP media IISD, which can be seen at https://enb.iisd.org/carbon-capture-storage-africa-emerging-economie and a recording available at the UNFCCC Youtube channel. This was well attended with around 100 in-person attendees plus more online. Judging by the good questions and follow on discussions afterwards, it was very well received.



Our second side-event, organised with the University of Texas and hosted by the Clean Air Task Force in their pavilion, was on CCS in the Caribbean. Colleagues from Trinidad and Tobago sharing their progress and learnings with other countries, including an example presented from Guyana, showing Trinidad and Tobago becoming the centre of CCS expertise for the Caribbean region. We were fortunate to have the Ministry of Energy involved at the highest level, with Acting Permanent Secretary Mrs Sandra Fraser speaking. This event was considered a success by all that went and was well attended.

Tim Dixon (IEAGHG) and US Secretary of Energy Jennifer Granholm at the CDR Launchpad.

There was a "CDR Launchpad" event in the second week, to launch the "CDR Sprint" announced in GCEAF Pittsburgh. Participating governments include Canada, European Commission on behalf of the European Union, Japan, Norway, United Kingdom, and United States.

Speakers at the UNFCCC CCS side event at COP27.

This 'Launchpad' will provide a platform for countries to share experience and learnings to develop CDR projects faster and more effectively, help ensure that standards and policies enable CDR technologies to develop swiftly, equitably, and responsibly, and amplify CDR investment to leverage the impact of government resources devoted to this effort.

The CDR Launchpad is a 'sprint' of the Mission Innovation CDR Mission, which was launched at COP26 last year. CDR Launchpad members agree to build at least one 1,000+ tonne/year CDR project by 2025, and share data from these projects, and to contribute to cumulative investment of USD 100 million collectively by 2025 to support CDR demonstration projects. The CDR Launchpad was launched by the US Secretary for Energy, Jennifer Granholm, the UK Minister for Climate, Graham Stuart, and the Canadian Assistant Deputy Minister for Environment and Climate Change Stephen de Boer. It was an honour for IEAGHG to be invited to moderate a discussion panel on the benefits of a globally-coordinated, rapid increase in large-scale CDR demonstrations.

Ministers and other dignitaries at the CDR Launchpad event.

IPCC

IEAGHG are accredited as Observers to the IPCC, so that we can improve our opportunities for input. The IPCC is currently in its Sixth Assessment cycle. IEAGHG focusses most of our input to IPCC's Working Group III (Mitigation). The Synthesis Report of AR6 brings together all three underlying reports from WGI, WGII and WGIII. The First Order Draft was issued for expert review on the 10th January 2022 with a deadline of 20th March 2022. The final version of WGIII had not then been published, so it was impossible to check against that, but IEAGHG submitted eight comments (mostly corrections on DACCS).

The WGIII report was published in first week of April 2022 and we were pleased to see that our nearly 100 substantive Expert Review comments had been acted upon, and IEAGHG reports and papers cited. We produced two Information Papers to summarise the CCS-relevant messages (2022-IP03 and 2022-IP05). These summarise the WGIII key messages as follows. We need immediate and deep reductions across all sectors otherwise 1.5°C is out of reach. Options described to reduce emissions focus on the high-emitting energy and industry sectors. Some mitigation options can reduce environmental impacts, enhance health and increase employment and business opportunities. As climate change is the result of more than a century of unsustainable energy and land use, lifestyles and patterns of consumption and production, the report shows how taking action now can move us towards a fairer, more sustainable world. In the energy sector major transitions are required and reducing fossil fuel use and using CCS is a leading option listed, followed by the other low-carbon options. Decarbonising the transport sector relies substantially on decarbonising the power sector. Achieving net zero in industry sectors is challenging, but CCS is a solution. CDR will be necessary to achieve net-zero and engineered CDR such as DACCS and BECCS need to be proven at scale, and to have agreed monitoring, reporting and verification (MRV) of its GHG achievements.

As well as working on CCS for 30 years, IEAGHG is increasingly working on engineered CDR, including DACCS, and addressing the issues emphasised by this new IPCC report.

London Protocol

The London Convention and the London Protocol are the global marine treaties that protect the marine environment. We previously reported on the CCS amendments and the 2019 Resolution to allow export of CO_2. In 2021 to provide easier access to and understanding of the London Protocol's detailed guidance and guidelines for export of CO_2 for offshore storage, IEAGHG produced a report, IEAGHG 2021-TR02.

For the annual meetings of the Parties, IEAGHG are the only CCS-related organisation attending.

For LC44 in 2022, for the CCS agenda item in terms of the 2009 amendment for CO_2 export, three more countries have accepted the amendment (Denmark, Korea, and Belgium, so there are now ten Parties who have accepted the amendment. Increasing but still very short of the two thirds needed of the 53 Parties to the London Protocol for it to come into force. This is why the Resolution on Provisional Application in 2019 was needed to allow export of CO_2 for offshore geological storage ahead of the coming into force of the 2009 amendment.

Seven countries have now deposited declarations on this Provisional Application (Belgium, Denmark, Netherlands, Norway, Korea, Sweden and the UK). Under the CCS agenda item, which calls for updates on relevant activities, IEAGHG reported by submitting an information paper on updates on offshore CO_2 sequestration (as CCS is known in the LC).

Under the Marine Geoengineering agenda item, the status of the 2013 amendment to regulate marine geoengineering is that it has been accepted by only six Parties, far short of the number needed for it to come into force.

Previously IEAGHG has attended these meetings on the OECD/IEA's delegation. In 2022 IEAGHG formally applied to be an accredited observer in its own right, and this was approved at the LC44 meeting.

CSLF

The Carbon Sequestration Leadership Forum (CSLF) is a government-to-government agreement on developing CCS, it started in 2003 and now has 25 member countries and the European Commission. IEAGHG and the CSLF Technical Group have an agreed 'Collaborative Arrangement' since 2007, and IEAGHG has produced nine reports from three studies and six workshops for the CSLF.

The CSLF Technical Group held its 2022 meeting in-person on the 27 June in Bergen. The significant items from this meeting were the CSLF endorsement of three new projects: Lafarge's CO2MENT cement CCS project in BC Canada, the Porthos project in the Netherlands, and the Northern Lights project. Also the recognition of achievement of three existing projects: Boundary Dam, Tomakomai, and Technology Centre Mongstad (TCM). In addition, a panel was held to discuss the learnings from Boundary Dam, Norcem, Tomakomai, Northern Lights and Alberta Carbon Trunk Line. Northern Lights' and Norcem's learnings were particularly new and interesting, as they are in their construction phases. Another panel was held on test centres and their role in speeding up CCS deployment, moderated by IEAGHG.

The following CSLF Task Forces reported updates: CDR; Offshore CCS workshop series (by IEAGHG and University of Texas); Hubs and Clusters; Technology Roadmap; and plans for a CSLF workshop in Central and Eastern Europe in 2023.

A site visit to the Northern Lights CO_2 Receiving Terminal was included. This place will go down in CCS history as the first of its kind in the world, being able to receive and store CO_2 from anywhere in the world. It was impressive to see the progress made as it is now in construction, compared with our previous visit in February 2020 with the 4th Offshore CCS Workshop when we were the first international group to visit. Discussions at this 2022 visit resulted in a live-remote tour being provided in plenary at GHGT-17, which was appreciated by attendees not yet able to visit the site.

CDR workshop

A CSLF Workshop on Carbon Dioxide Removal (CDR) was held on the 28th June 2022. IEAGHG was on the Steering Committee which was lead by Australia. In the keynotes IEAGHG's work featured significantly, with IEAGHG's Jasmin Kemper providing an overview of CDR technologies, and IEAGHG's recent reports on DAC and on CO_2 Mineralisation being presented with Imperial College's work on BECCS. Technology providers and project developers were invited to present and we heard from MCi, Drax, Climeworks and Celsio (the new company name for the Fortum Waste to Energy plant). Celsio's fuel is 50% biogenic and so will create negative emissions.

IEAGHG chaired a discussion panel on CDR accounting. This discussion recognised the compliance and the voluntary carbon markets, the need for CDR MRV methodologies, and the gap in the IPCC GHG Inventory Guidelines for DAC which is required for the compliance markets.

IEAGHG and the CEM CCUS Initiative moderated the workshop to agree key messages, conclusions and recommendations and a report of the workshop was published by IEAGHG (2022-TR04).

For full CSLF agendas and presentations, see 2022 Technical Group Mid-Year Meeting | CSLForum.

ISO TC/265

This ISO committee was proposed by Canada and set up in 2012 with a Canadian Chair and Canadian and Chinese Secretariat. There are 19 participating countries, 13 observing members, and 7 Liaison organisations.

It consists of seven working groups: WG 1 Capture; WG 2 Transport by Pipeline; WG 3 Storage; WG 4 Quantification and Verification; WG 5 Cross-cutting issues; WG 6 CO_2-EOR; WG 7 Transport by ship (new in 2022). IEAGHG is a Liaison Organisation to TC265, and is a member of WG 3 and WG5. The last plenary was held virtually on the 23rd June 2022. IEAGHG provided an update to input our technical reports.

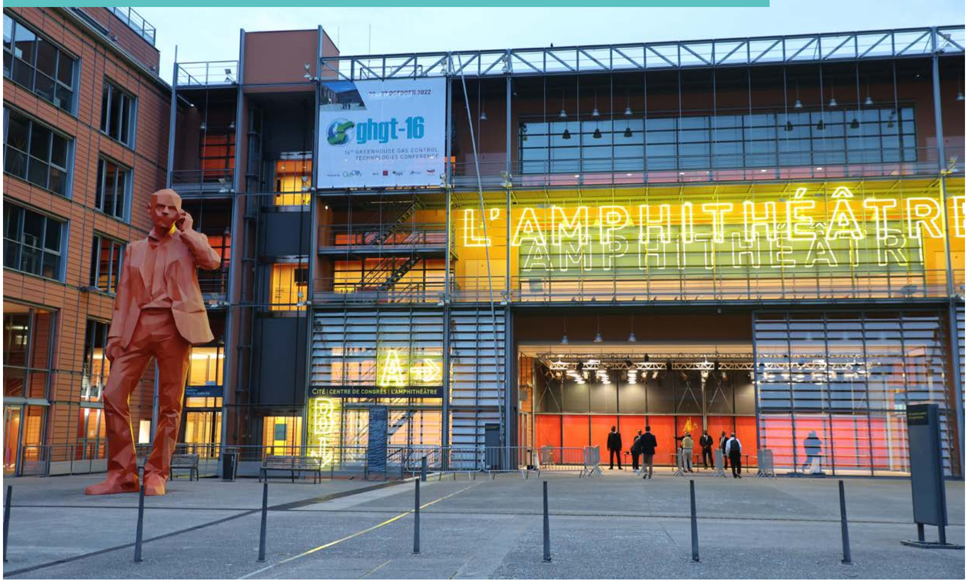
More information is available at: ISO - ISO/TC 265 - Carbon dioxide capture, transportation, and geological storage.

IEAGHG Conferences 2022

GHGT-16: Lyon, France

In acknowledging the importance of carbon capture, utilization and storage (CCUS) to reduce CO_2 emissions and meet the Paris Agreement's objectives, the French IEAGHG members were selected to host the 16th International Conference on Greenhouse Gas Control Technologies (GHGT).

The conference centre for GHGT-16.



This was the first time the GHGT conference had been held in France, and therefore provided the platform to truly showcase France's (and more broadly Europe's) expertise in CCUS and support the future CCUS developments across Europe, especially regarding applications in the industry sector. The Conference host 'Club CO_2' composed of: ADEME, BRGM, IFP Energies nouvelles and TotalEnergies, selected the city of Lyon the 2nd largest metropolitan area (after Paris) in France and the 1st European capital of smart tourism (voted in 2019). Making it an ideal location for travel and accommodation for delegates who were now eager to connect in a safe face to face conference environment, and enjoy the heritage and gastronomy of the fabulous city.

The conference took place from 23-27 October and was attended by more than 1200 delegates from 58 countries. Over the four days delegates had access to more than 700 presentations in the technical sessions, including the E-poster presentations and panel discussions covering topics varying from policy, developing countries, repurposing, upstream emissions and the Middle East.

Keynote presentations on the opening day were given by major voices in the field: Ms Thelma Krug (Vice Chair of IPCC), Mary Burce Warlick (Deputy Executive Director of the IEA) and Mr Jarad Daniels (CEO of GCCSI). Technical plenary talks on the consecutive days were given by Ms Christine Healy (Senior Vice President, Carbon Neutrality and Continental Europe of TotalEnergies), Dr Jennifer Wilcox (Principal Deputy Assistant Secretary in the Office of Fossil Energy and Carbon Management at US Department of Energy), and Mr Matt Crocker (Senior Vice President of Low Carbon Solutions ExxonMobil).

The generous sponsorship of the conference ensured delegates benefitted from lower registration fees and some spectacular social events. On Sunday the welcome reception took place at the beautiful Palais de la Bourse, built in 1862 as the centre of commerce, and then on Wednesday delegates were transferred by bus to the sit-down gastronomic gala dinner and entertainment in the unusual setting of La Sucrière, a sugar storage facility now used in Lyon for hosting major events.

IEAGHG Chairman Kelly Thambimuthu welcomes delegates to GHGT-16.

IEAGHG would like to thank all of our GHGT-16 Sponsors

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During the evening the prestigious 'Greenman' awards were presented to recipients:

Trude Sundset (Strategic Advisor and Business Development at Aker Horizons), and Professor Ed Rubin (Carnegie Mellon University)

for their many years of dedication to research and development to the CCUS industry.

We thank all our sponsors - TotalEnergies, ExxonMobil, OGCI, Air Liquide, TCM, MHI Heavy Industries, Equinor, US DOE, Holcim, Gaffney Kline, Baker Hughes and Eccsel Eric.

The next GHGT conference will take place in Calgary, Canada from 20-24 October 2024 hosted by Emissions Reduction Alberta (ERA) in the TELUS Conference centre. Call for abstracts will open in September 2023 with registration for delegates opening in March 2024 for Early Bird rates.

Risk Management Network – Webinar & Virtual Discussion: The Road to CCS Project Permitting – Operators' Experiences With Risk Management During the Permitting Process

On Tuesday 18th January 2022, the IEAGHG Risk Management Network held a webinar which aimed to be a roundtable presentation of CCS / CCUS (carbon capture and storage / carbon capture, utilisation and storage) project operator experience, with risk management, during the permitting process.

This webinar was organised by the IEAGHG Risk Management Network, which aims to bring worldwide experts together to discuss topics pertinent to the risk management of CCS / CCUS projects including risk analysis, risk data management, regulatory engagement and impacts of activities.

This webinar heard from panellists on the Northern Lights project, the Porthos project, California experiences with permitting and Oxy's recent project experiences.

The webinar attracted an audience of 138 in addition to 8 panellists and 2 IEAGHG staff. It included an informal roundtable discussion to learn about the experiences that project operators have had relating to risk management during the permitting process. It provided an understanding of the challenges faced and explored potential ways to overcome such issues for future permits. The virtual event welcomed speakers from CCS projects and industry to hear their views and learn more about the challenges they have faced, specifically when going through the permitting process.

A full review of the webinar was produced by IEAGHG to summarise the discussions and draw out main conclusions. This can be requested from IEAGHG, quoting report number 2022-TR02.

14th IEAGHG International Summer School

Held from the 27th November to the 4th December 2022 in Bandung, Indonesia, and hosted by ITB, the 14th IEAGHG International CCS Summer School brought together 44 students from 15 different countries to learn about all aspects of CCUS.

Students learned through an intensive programme of technical lectures, interactive workshops, group work and field trips covering the entire CCUS value chain, delving into the topics listed below:

- Climate change and the global CCS scene
- CO_2 capture technologies
- Storage of CO_2
- Modelling
- Monitoring and verification
- Environmental impacts of capture and storage
- Wellbore integrity
- Risk and uncertainty, health and safety
- Transport of CO_2 and hubs
- Utilisation of CO_2
- Hydrogen and CCS
- BECCS, negative emissions and DAC
- Costs, economics and financing of CCS
- National and international policy, legal and regulatory carbon accounting
- Public communication, engagement and social media

The group work throughout the week tasked the students with providing an evaluation of pre-set questions requiring research, collaboration, consensus and compromise, with the Friday of the School dedicated to group presentations and subsequent questioning by an expert panel. This year, group 4 won the 'best group' award with their exciting, informative and humorous debate on 'should CCS be mandatory in developed countries?'

In addition to the group work, students were observed throughout the week for the chance of being selected as one of two 'most outstanding students', and its congratulations to Katherine Jimenez (NORCE, Norway) and Debanjan Chandra (Delft University of Technology, the Netherlands) for winning the title this year.

Students & Lecturers at the 14th IEAGHG Summer School, Bandung, Indonesia, December 2022.

Of course, the IEAGHG Summer School could not go ahead without international experts in CCS giving their time to join as speakers and / or expert mentors. IEAGHG would like to thank our speakers from CO2CRC, ExxonMobil, Gassnova, GCCC at the University of Texas, Imperial College, the International CCS Knowledge Centre, ITB, IIASA, JPower, University of Pertamina, Shell, TotalEnergies and the US DOE. In particular, a huge thanks goes to our expert mentors who volunteered their time to be with us in Indonesia for the entire week: John Kaldi (CO2CRC), Rachmat Sule (ITB), Katherine Romanak (GCCC, BEG at University of Texas), Tim Dixon (IEAGHG), Mark Wood (Shell), Ganesh Dasari (ExxonMobil), Sri Intan Wirya (ExxonMobil), Shinichi Sakuno (JPower), Farah Mulyasari (University of Pertamina), Haposan Napitupulu (Essa) and Aqsha (ITB).

We also like to thank the sponsors of the IEAGHG Summer School for their support of the event. Firstly, to our Series Sponsors BEIS, Gassnova CLIMIT, Swiss Federal Office of Energy, TotalEnergies, Shell, and ExxonMobil, for their ongoing support over the years. Thanks also to this year's Local Sponsors: KPI, BP Indonesia, Essa, INPEX, Technip Energies, Pertamina, Samator, Halliburton and WAVIV.

And finally, a very big thanks to our hosts, ITB, and in particular Dr Rachmat Sule and his incredible team of assistants who helped make this another successful Summer School in the IEAGHG series.

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IEAGHG Technical Studies 2022

2022-01 Criteria for Depleted Reservoirs to be Developed for CO_2 Storage, report managed by Samantha Neades

The long-term, secure storage of CO_2 depends on injection and retention within well characterised geological reservoirs, such as saline aquifers or depleted oil and gas fields. Depleted oil and gas reservoirs are often selected for first-generation CO_2 storage sites because they have been characterised from their discovery date, during the whole production phase and possibly during post-production observations.

The potential CO_2 storage capacity in saline formations is well understood, and so the objective of this study is to specifically focus on a set of storage conditions that apply to depleted oil and gas fields. The study is split into three main sections: a review of case studies for CO_2 storage in depleted hydrocarbon fields; original research looking into reservoir pressure depletion, boundary conditions, the effect of residual hydrocarbons on injectivity and capacity; and the economics of infrastructure reuse for CO_2 storage sites. The third section discusses and integrates the lessons learned to facilitate evaluation of future depleted field storage opportunities.

Key Messages

- Depleted hydrocarbon fields are valuable and advantageous sites for the storage of CO_2.
- Site evaluation when considering depleted fields for storage should be project-specific and should consider the storage requirements and the operators' metrics for success and views of acceptable risk.
- Sub-hydrostatic reservoir pressure is a sign of closed or semi-closed reservoir boundaries and such reservoirs may offer greater storage security but also place limits on capacity.
- The presence of remaining hydrocarbon gas in place does not necessarily affect the CO_2 storage capacity of the depleted dry gas reservoirs, other than occupying pore space.
- The majority of a CO_2 plume in a depleted dry gas reservoir remains mobile, while capillary and dissolution trapping mechanisms play minor roles in trapping.
- Other than occupying pore space, the amount of remaining gas in place does not significantly affect the capillary and dissolution trapping efficiency of CO_2 plume in a depleted dry gas reservoir.
- Infrastructure reuse, based on a comparison of modelled examples, will not always result in lower costs for CCS projects.
- In all projects, outreach and public relations are crucial for reassurance.
- The best scenarios for CO_2 storage in depleted fields may be 'hybrid' situations, such as CO_2-EOR or injection into the water leg down-dip of a depleted reservoir.
- The report includes key guidance on Site Evaluation and Desirable Characteristics.

2022-02 Current State of Knowledge Regarding the Risk of Induced Seismicity at CO_2 Storage Projects, report managed by James Craig

This study reviewed the risk of induced seismicity at CO_2 storage sites. The phenomenon has multiple causes including waste water disposal, geothermal energy and mining. Natural seismicity is also a widespread occurrence and can detected in the same regions as industrial activities associated with induced seismicity. Consequently the detection of any seismicity has to be clearly distinguished. This study has compiled evidence from microseismic detection techniques used at demonstration CO_2 storage sites and what can be interpreted from them.

Key Messages

- Investigation into the link between induced seismicity and very large-scale waste water disposal has advanced significantly since the 2013 IEAGHG review of induced seismicity. Seismic monitoring of CO_2 storage sites has also led to a better understanding of the phenomenon especially the propagation of microseismic events.
- The use of sophisticated monitoring techniques has been refined and enabled enhanced event location and improved model calibration. Evidence from microseismic detection techniques at demonstration CO_2 storage sites has also revealed temporal correlations with periods of high injection rate and bottom-hole pressure. There is no evidence of felt seismicity at any of the 36 CO_2 storage sites reviewed in this study with the exception of one CO_2-EOR (enhanced oil recovery) site.
- Monitoring microseismicity at CO_2 storage sites has revealed events are more common during perturbations in flow, including shutdowns, than they are during injection.
- The analysis of geomechanical responses in reservoirs can contribute to the assessment of the risk of felt seismicity caused by pressure perturbations within a project area. Geomechanical modelling is therefore of critical importance and requires verification with measured parameters.
- Large-scale waste water disposal has a clear association with induced seismicity across some regions of the south - central US. However, it is important to recognize that natural pre-existing tectonic stresses can be triggered by pressure changes induced by fluid injection. Some regions of the US, such as North Dakota near the Canadian border, and in the northeast US, exhibit a relative lack of felt seismicity, despite waste water disposal.
- Historical evidence, that predates large-scale waste water disposal, also shows that natural tectonic activity has been responsible for seismicity across the south – central and other regions of the US.
- Waste-water disposal intervals at a depth of ~2km, for example in Oklahoma, can have related seismic hypocenters at an estimated depth of ~5km in the crystalline basement.
- Other factors can complicate when seismic events might occur. Stress can be transferred to deeper fault zones that are critically stressed and susceptible to slip. This mechanism may have been responsible for the Castor event off the north-east coast of Spain. Earthquake to earthquake interaction is also possible where accumulated stress from previously seismically non-active regions can be affected.
- In response to concerns associated with induced seismicity in the US a series of precautionary operational measures were introduced. These have included mandatory injection into higher stratigraphic formations, significant volumetric reductions in waste water injection or, in some cases, complete cessation and a ban on new disposal wells in close proximity to known regional faults. Seismic monitoring plans also need to be implemented and include tests to detect the presence of faults. Specific regulations depend on each state.
- Regulatory authorities have defined rules and expectations for permits, incorporating in most cases, past earthquake data (distance of seismicity from the well and magnitude of events) and characterization of subsurface hazards. In some cases (Canada, Oklahoma, Ohio, UK), the operator has to follow a traffic light system that "controls" its actions and provides guidance on risk mitigation based on an earthquake magnitude threshold. This depends on each country or state.
- Causes of seismicity at specific locations need to be clearly explained especially to local communities that may be affected by CO_2 storage sites. For example, in Japan natural seismicity is a regular occurrence, and felt events are not uncommon, consequently the origin of such events needs to be conveyed so that they cannot be associated with a CO_2 storage site. In another example, and in contrast, geothermal energy produced from the Geysers field is actively monitored because of the link between the field's operations and induced seismicity. Successful proactive outreach policies at the Tomakomai CO_2 storage demonstration site in Japan, and the Geysers geothermal field in California, have demonstrated how seismic origin, and its potential impacts, can be effectively communicated.

2022-03 Prime Solvent candidates for next generation of PCC plants,
report managed by Abdul'Aziz Aliyu

Research, development, demonstration, and deployment of advanced solvents is at the forefront of decarbonising the fossil fuel combustion sectors with the aim of making solvent-based CO_2 capture more competitive in a net zero economy. Considering the extensive research in solvent design and development, a rapid and reliable screening protocol is imperative for new solvents and process configurations to be ranked against existing systems.

In light of the importance of vetting promising solvents for PCC, IEAGHG commissioned this study: "prime solvent candidates for the next generation of post-combustion carbon capture (PCC) technology 2022-03, March 2022". The main objective of the study is to conduct a comprehensive assessment of the promising PCC solvents and process designs to accelerate the deployment of CO_2 capture technologies. This study further provides an analysis of the enhancement of PCC solvents and their potential functionality under standardized metrics to measure the solvents performance and their impact on capture costs including both capital expenditure (CAPEX) and operational expenditure (OPEX).

An exhaustive literature survey of solvents for PCC led to the creation of a solvent database named CO_2SOLV which comprises of 842 entries of various type of solvents that include aqueous amine solvents, solvent blends, water-free/water-lean solvent and biphasic solvents. It contains detailed properties of >107 solvents plus several process configuration and modification schemes. This database includes publicly available information on installations testing solvents (at large, pilot and lab scale) for PCC, in addition to solvents reported in scientific publications and patents. This study developed a decision-matrix-tool to enable the comparison of the different solvents and processes based on Key Performance Indicators (KPIs). These performance indicators include monetised and non-monetised parameters/variables such as cyclic absorption capacity, heat of regeneration, solvent viscosity, enhancement indexing, heat capacity, degradability, surface tension, solvent cost, absorber sizing, reboiler temperature, among others.

The key messages from this study are as follows:

- Based on the collected data and their detailed analysis, no single amine was identified to have an overriding superior performance in terms of capital and operating costs. Most of the amines spanned between slightly better and poorer performance compared with MEA in terms of both capital and operating expenditures. The most promising amines were found to be 2-(isopropylamino) ethanol (IPAE), aminoethylethanolamine (AEEA), 2-methyl piperazine (2-MPZ), 2-(ethylamino) ethanol (2EAE), 2-amino-1,3-propandiol (2APD), 3-(methylamino) propylamine (MAPA), piperazine/2-amino-2-methyl-1-propanol (PZ/AMP) and monoethanolamine/ethylene glycol (MEA/EG).
- The solvent properties that have the most influence on the capital cost are the absorption capacity, reaction rate, absorption enthalpy (heat of absorption) and the liquid viscosity.
- In terms of process configurations, the most promising modifications include absorber inter-cooling, rich solvent split, stripper overhead compression, split flow, and lean vapour compression as per the reduction in the specific reboiler duty.
- In terms of process configurations, the most promising modifications was found to be absorber inter-cooling, rich solvent split, stripper overhead compression, split flow, and lean vapour compression as per the reduction in the specific reboiler duty. However, a techno-economic analysis is needed to account for the possible trade-off in the capital costs.
- Integration of two or more process modifications can potentially induce positive interactions and synergy in maximizing effects and mitigate offsets. Dual process integration showed various impacts on the overall process with a reported reduction of the specific reboiler duty (SRD) ranging from 11% to 39% when simulating MEA. Further study to evaluate the behaviour of other emerging solvents under the influence of multiple process modifications is expected to yield lower SRD. However, new research is expected to reveal the extent of savings in terms of the relevant indicators like SRD.

2022-04 From CO_2 to Building Materials - Improving Process Efficiency,

report managed by Samantha Neades

Decarbonising the economy through CCUS relies not only on viable methods to capture CO_2 but also efficient usage and/or storage of that CO_2. In some instances, e.g. where large transport distances are required, or for countries which do not have large geological storage resources, utilising the captured CO_2, or carbon capture and utilisation (CCU), may be the most effective way to decarbonise rather than transporting to a storage site.

This study investigates how captured CO_2 may be used in building materials and explores the processes used to capture the CO_2. The study looked into the effects of carbonation on material utilisation, the design of a potential typical carbonation plant, and undertook a market analysis of carbonated building products. This study offers a valuable insight into how captured CO_2 can be used in building material, with several key messages including:

- Accelerated carbonation products have the potential to be used as aggregates, fillers, reactive fillers, and supplementary cementitious materials (SCM).
- Carbonation is a relatively expensive method of CO_2 utilisation unless there is substantial avoided cost associated with raw material disposal.
- There is a degree of discrepancy between theoretical and experimental uptake rates for different materials. The measured CO_2 uptake is significantly lower than an estimation based solely on composition.
- It is important to consider the inherent trade-offs between each potential use – carbonating materials or use as an SCM.
- In many cases, carbonated materials should be preferentially used as a supplementary cementitious material or otherwise blended in to cement where possible.
- Non-Portland cementitious materials are frequently carbonated and can be used as an additive to cement and contribute to strength development in the final product. Note that the total amount of CO_2 present in the cement should generally not be too high as it can reduce the pH of the cement binder and dilute its cementitious properties.
- Natural carbonation processes will occur which will reduce the additionality of accelerated carbonation.
- Carbonation can act as a waste treatment process, stabilising heavy metals.
- The main driver for carbonation processes is the avoidance of landfill costs where applicable.
- Current market prices suggest that the market for carbonated products is limited and will be closely linked to robust CO_2 pricing mechanisms that recognise and value the mitigation service of carbonation.
- Further research is needed both to understand the potentials of more novel carbonated materials to store CO_2, and their production processes, as well as to understand their material properties.
- There is currently insufficient pull from the construction industry for carbonated or low carbon emission produced products.

2022-05 Feasibility study on achieving deep decarbonization in worldwide fertilizer production, report managed by Abdul'Aziz Aliyu

Food production is expected to increase due to global population growth and, consequently, fertilizer production will be essential for global food security.

Currently, the CO_2 emissions linked to fertilizer production are approximately 400 Mt/year (over 1% of global energy-related CO_2 emissions) with a predicted growth to 550 Mt/year by 2050. Fertilizers are basically produced from ammonia. It then follows that the feedstock used in ammonia production will be significant in the energy consumption and CO_2 emissions produced during food production.

To limit the impact on the environment caused by the current ammonia production routes, which rely significantly on fossil fuels both as an energy source and as feedstock, sustainable production pathways need to be implemented. Since only nitrogen and hydrogen are required for ammonia synthesis, there are few variables for process optimization. The conventional steam methane reforming (SMR) hydrogen production route is one of the primary variables in the environmental impact of the ammonia process. The application of carbon capture on the production of fertilizer is recognized as one of the least-cost methods of capturing CO_2 from a thermodynamic and process perspective; and is equally attractive as it also has one of the lowest cost impacts on the price of the commodity.

IEAGHG commissioned a study on the ‘Feasibility Study on Achieving Deep Decarbonization in Worldwide Fertilizer Production" to provide an overview of fertilizer production processes with and without CO_2 capture. Assessment of the identified fertilizer production processes from a broader environmental perspective was also included. Further, this study analysed the results and has provided recommendations on how deep decarbonization of fertilizer production can be achieved for regions such as Europe, North America, and the Middle East.

Three ammonia production routes for fertilizers are analysed and compared as follows:

- Case 1: Production of ammonia from natural gas without CO_2 capture from SMR flue gases (base case)
- Case 2: Production of ammonia from natural gas with CO_2 capture from SMR flue gases
- Case 3: “Hybrid” production of ammonia from water electrolysis (partial) and natural gas, with CO_2 capture from SMR flue gases.

This study has highlighted the decrease of direct CO_2 emissions from the ammonia process derived from CO_2 capture. Specifically, the highest environmental benefit was gained from where an impact reduction of up to 70% was observed. In UK, USA and Saudi Arabia the impacts decreased by 53%, 40%, 33% respectively. In general, the results of this study implied that the environmental impacts of the fertilizer production routes investigated are mainly affected by energy (natural gas and electricity) demand and the related supply chain. The Norwegian case study was found to be the most sustainable option for fertilizer synthesis due to its significant environmental savings compared to other three cases in this study.

2022-06 Blue Hydrogen: Beyond the Plant Gate, report managed by Abdul'Aziz Aliyu

The momentum behind the hydrogen economy is unprecedented with government policy announcements to corporate commitments, and consortia and projects synergies. There is currently a global cognizance with regards to how low carbon hydrogen is critical to achieving the climate goals of limiting the global temperature rise to 1.5 °Celsius.

In spite of the well-established hydrogen production technologies from organic feedstocks hydrogen production from oil and oil-based products (which could represent an additional and interesting source of production of hydrogen and bring forth potential cost reductions in the blue hydrogen price) has not been fully explored to date.

Consequently, IEAGHG commissioned a study entitled "Blue Hydrogen – Beyond the Plant Gate" with the aim of producing a comparative analysis of blue hydrogen production (that is hydrogen derived from fossil fuels and associated CCS) technologies from oil and oil-based feedstocks as well as the supply chain implication.

To address key knowledge gaps in blue hydrogen production pathways, this study was conducted in parallel with a second study titled 'Low carbon hydrogen from natural gas: Global Roadmap", which focusses on the technical, economic, and environmental impact of hydrogen production routes from natural gas with associated CCS. Eight selected hydrogen production technologies, which use oil and/or oil-based products as feedstocks, are reviewed in this study. These technologies with their respective TRLs (technology readiness levels) include catalytic naphtha reforming (9), pyrolysis (4-8), plasma reforming (4), diesel reforming (3-4), HyRes (3-4), steam naphtha reforming (9), partial oxidation (9) and hygienic earth energy (4-6). Steam naphtha reforming (SNR), partial oxidation (POX) and hygienic earth energy (HEE) were selected for further techno-economic and life-cycle analysis in this study.The potential for oil-based blue hydrogen production technologies in terms of CO_2 transport and storage (T&S) options, feedstock availability, and access to hydrogen markets, were conducted in fifteen countries across five regions as follows:

- Middle East – UAE, Saudi Arabia, Kuwait, Iraq, and Iran
- West Africa – Nigeria, Equatorial Guinea, Gabon, Republic of Congo, and Angola
- North Africa – Algeria and Libya
- Latin America – Brazil and Venezuela

This study has demonstrated that there are pathways to competitively produce hydrogen derived from oil and oil-based products when compared to the other mainstream alternatives such as hydrogen derived from natural gas and/or electrolytic hydrogen. The competitive potential of the three studied technologies are as follows:

- SNR: This technology has the potential to be deployed close to a refinery which supplies Naphtha. SNR cost is, however, 118% higher than SMR in Netherlands because of the high feedstock cost. Therefore, this technology is competitive when cost of naphtha is lower than natural gas.
- POX: This technology can readily be deployed close to a refinery which can supply a vacuum residue. POX has the advantage of utilising other waste oil products as feedstock, consequently improving its economics.
- HEE: If this technology is proven, it has the potential for dedicated hydrogen production from depleted oil reservoirs. Further, HEE has a competitive edge in regions where SNR and/or POX are costly.

A potential competitive pathway for hydrogen derived from oil and oil-based products against other mainstream alternatives could be achieved if the hydrocarbon feedstock is treated as a waste product (vacuum residue) or assuming it has no inherent economic value (retained within a depleted reservoir).photovoltaics (PV) costs are used, or ~$350-$550/net-tCO_2, when lowest-cost renewables are used.

2022-07 Low-Carbon Hydrogen from Natural Gas Global Roadmap,
report managed by Abdul'Aziz Aliyu

In light of the need to address pertinent knowledge gaps with regards to the key aspects of blue (CCS-abated) hydrogen deployment, IEAGHG commissioned two parallel blue hydrogen studies.

The second of the studies, "Low carbon hydrogen from natural gas Hydrogen - Global Roadmap". appraises the life cycle emissions and the techno-economics of SMR (TRL 9) + CCS, ATR (TRL 7 - 9) + CCS, ESMR (TRL 4) + CCS and POX (TRL 9) against the benchmark conventional SMR (with no associated CCS) in the Netherlands.

The key messages from the low carbon hydrogen from natural gas are as follows:

- The life cycle assessment (LCA) for the natural gas-based blue (CCS-abated) hydrogen productiontechnologies reveals that a reduction of the carbon footprint ranging between 43-76% can be achieved in the Netherlands in 2020 for all the investigated technologies. This reduction is set against the reference grey (without CCS) hydrogen with a carbon footprint of 10.13 kg CO_2 eq./kg H_2.
- The carbon footprints of blue hydrogen produced using SMR (2.78 kg CO_2 eq./kg H_2), ATR + GHR (3.23 kg CO_2 eq./kg H_2) are comparable to that of POX, with POX (2.43 kg CO_2 eq./kg H_2) achieving the lowest carbon footprint. In contrast, blue hydrogen produced using ESMR has the highest carbon footprint (5.74 kg CO_2 eq./kg H_2). This is primarily because of the significant utilisation of the carbon intensity of electricity in the Netherlands (480 gCO_2/kWh in 2020).
- Direct CO_2 emissions (reaction emissions and emissions related to combustion of natural gas), natural gas production and transport as well as grid electricity, were found to be important contributory factors in the carbon footprint of the blue hydrogen production pathways. The most influential factor on the carbon footprint of hydrogen produced via SMR + CCS was the natural gas production and transport. The largest contributing factor of the carbon footprint for ATR + gas heated reformer (GHR) + CCS, ESMR + CCS and POX, in this study, was the source of electricity utilised to run these thermochemical processes.
- The carbon capture rate has a significant impact on the carbon footprint of the blue hydrogen production technology. The overall carbon footprint of hydrogen produced with the SMR technology is reduced by 8% when the carbon capture efficiency is increased from 90% to 99%, this is despite the increase of electricity usage increase by 10%.
- An increase of the carbon footprint of natural gas by 171% and 29% were observed for natural gas imported to the Netherlands from Russia and Algeria respectively.
- The projected reduction in carbon footprint for different technologies varied significantly from 12% for SMR + CCS to 54% for ESMR + CCS by 2030.
- All the four investigated technologies were observed to be most sensitive to feedstock/fuel costs and the price of CO_2 T&S. SMR was also found to be highly sensitive to increasing carbon prices because this technology exhibits the lowest CO_2 capture efficiency amongst the studied technologies. In contrast, ATR, POX and ESMR are observed to be largely sensitive to electricity costs.
- POX is the most cost-effective process for avoiding CO_2 emissions, whereas ESMR is the highest cost in Netherlands in 2020. SMR and ATR both have a cost of CO_2 abatement of about €110/tCO_2, which is about 28% higher than POX and between 9% to 25% lower than ESMR (with grid and renewable electricity respectively).
- By 2050, the investigated blue hydrogen production technologies have between 17% to 31% lower LCOH against the reference case. In this case scenario, significant reduction of the cost of CO_2 T&S for all technologies is realised as CCS projects are de-risked. Significant learnings are gained from numerous deployment projects and economies of scale are achieved.

2022-08 Start-Up and Shutdown Protocol for Power Stations with CO_2 Capture, report managed by Keith Burnard

In modern power grids, a power plant with CO_2 capture will be required to operate as a low-carbon, flexible, dispatchable power generator. With increased penetration of intermittent renewables, greater load-following is likely and a rise in the frequency of start-up/shutdown cycles would be expected.

If it transpired that frequent start-up/shutdown cycles resulted in appreciable CO_2 emissions, it could undermine the value proposition of including modern, flexible, dispatchable fossil fuel power generation assets in the grid even though CCUS applied to them could enhance energy security and grid resilience.

As limited work to-date has focused on the impact of start-up and shutdown of CO_2 capture plants, this study serves to broaden understanding of the dynamics of these processes, identifying key factors that impact CO_2 capture performance and operability.

Factors shown to be important include the solvent inventory volume, the initial start-up temperature (cold vs hot) and the timing of steam availability.

Using a larger solvent inventory can be beneficial in terms of maximising the cumulative CO_2 capture rate from start-up, through steady state operation and shutdown, particularly in the case of cold start-ups. Overall, hot start-ups showed a significantly higher cumulative CO_2 capture rate and lower specific reboiler duty compared to cold start-ups. The ability to sustain high CO_2 capture rates depends on the volume of the solvent inventory, the amine concentration, the starting solvent CO_2 loading, and the timing of steam supply to the reboiler.

Results demonstrated that, during start-up, any delay in steam supply to the capture plant significantly reduces the cumulative CO_2 capture rate, thereby greatly increasing the residual CO_2 emissions. Start-up with preheating was shown to be a potentially valuable approach. During hot start-up, measures such as high preheating and lower solvent loading, were shown to markedly improve capture performance. In the context of a net-zero energy system, the need for operational flexibility will rise. Hence, the ability to maximise the CO_2 capture rate during start-up and shutdown will be highly valuable as it reduces residual CO_2 emissions from power plants, thus easing the need for carbon offsets from CO_2 removal technologies, e.g., bioenergy with CCS, or direct air capture.

2022-09 Defining the Value of Carbon Capture, Utilization and Storage for a Low-Carbon Future, report managed by Keith Burnard

To limit global warming to well below 2°C, countries must achieve net-zero emissions by around mid-century. The energy transition needed to achieve this goal presents a daunting task for most countries.

To help inform the energy transition, IAMs have been used to identify the lowest-cost mitigation pathways for countries to achieve economy-wide, net-zero emissions. Under the current paradigm, there is a severe risk that mitigation plans will be based entirely around techno-economic assessments. However, the identification of a cost-optimal pathway reveals little about the feasibility of its implementation or of its economy-wide impact.

To achieve net-zero emissions by around mid-century, robust mitigation strategies will be required that work not only from a techno-economic or cost perspective but also from social, political and environmental perspectives. Without a more comprehensive, holistic assessment of the potential value of different mitigation options, the best-laid net-zero energy transitions strategies may be vulnerable to unanticipated (but, in many cases, avoidable) setbacks. They will also need to work at different levels, from the global to the company level. Developing a broader and deeper understanding of the potential 'value' of different mitigation options is one way to assess their robustness.

In this study, a more comprehensive assessment of the value of CO_2 capture, utilisation and storage (CCUS) technology was investigated. It was found that CCUS deployment created value from techno-economic, socio-technical and environmental standpoints and, in many cases, was found highly likely to enhance the robustness of long-term mitigation strategies and portfolios. Notably, CCUS deployment has the potential to help overcome many of the deployment challenges related to energy transitions, e.g., issues of land availability, siting restrictions, social acceptance and the potential for negative environmental impacts.

As governments commit to policies and develop long-term investment agendas related to energy transitions, it is increasingly important that such assessments are undertaken. In their absence, many parts of the world will be exposed to the risk of failing to achieve their mitigation goals.

2022-10 Mineral Carbonation using Mine Tailings – A Strategic Overview of Potential and Opportunities, report managed by James Craig

This report from IEAGHG is a review of the current status of mineral carbonation using mine tailings consisting of rock fragments that are known to be reactive with CO_2.

Many key industrial metals including nickel, chromium and platinum group metals (PMG) are associated with magnesium, iron and calcium rich silicate minerals that are known to be reactive with CO_2. The resultant carbonate minerals permanently lock CO_2 into solid phases. The key question is how rapid and effective is this process and can it be achieved economically without excessive additional energy. This review has critically investigated three decades of research on the subject as well as the most recent advances in industrial CO_2 mineralisation.

Key Messages

• Three decades of research and development work on accelerated mineral carbonation (AMC) has demonstrated that ultramafic, magnesium rich minerals in mine waste materials has the potential to sequestrate CO_2 via mineralisation. However, despite three decades of R&D most concepts have not advanced beyond Technology Readiness Level (TRL) 4.

• Although the stockpiled amounts of material are vast, the suitability of these materials is highly dependent upon specific conditions imposed by mineralogy, geochemistry, petrology, permeability and hydrology. AMC treatment and effectives is therefore highly site-specific.

• The limited scale-up from laboratory-scale investigation is partly due to the energy requirements and chemical kinetics to a timeframe of minutes rather than hours or days, as is still commonly being reported.

• Carbonation of mine wastes using CO_2 divided into two broad groups: direct carbonation, which often ends in struggling with a passivating silicate layer that prevents rapid chemistry and high conversion levels; while the second group focusses on stepwise extraction and conversion aimed at reaching higher conversion levels in shorter times.

• Extraction methods can produce materials of marketable value. The evidence from this review is that there are very few AMC approaches that could be economically viable at an industrial CO_2 mineralisation scale in a single facility.

• Although most AMC technology related to Mg rich waste streams is still at TRL 4 a few have progressed to TRL 6 or 7. One company, Mineral Carbon International (MCi), reported in 2021, that its aqueous process has advanced from TRL 6 to TRL 7. The company has received support to develop the technology subject to the results of final pilot studies and engineering designs.

• Calcium-based AMC has niche deployment opportunities as a result of the large markets for calcium carbonate based products. The relative reactive properties of calcium compared with magnesium means that the chemistry is less challenging than for conversions that produce magnesium carbonate.

• There have been very few cost assessments to determine the potential for commercial AMC deployment, even when possible revenues from the sales of metals or other by-products have been included. The most promising candidates for marketable products from AMC using magnesium silicate-type rock feedstock is nesquehonite ($MgCO_3 \cdot 3H_2O$). However, large-scale production could lower the price to uneconomic levels.

• There is a lack of reported evidence on the economic effectiveness of metal recovery from mine waste.

• Adverse environmental impacts caused by handling Mg-rich silicate host rocks include toxic metallic by-product streams, and other problematic solid, liquid or gaseous effluents, that can be produced by processing mine wastes. This aspect has received less attention.

• Life cycle assessment (LCA) tools are being increasingly used to quantify the environmental footprint of AMC. The technique does require impacts such as land use, water use and resource depletion as well as the benefits from a reduction in global warming potential.

• Deployment of large AMC facilities presents a public acceptance challenge which has yet to be adequately addressed. Experience from CarbFix does show that positive engagement with the public can produce favourable attitudes to power generation and associated environmental impacts. In this case subsurface *in-situ* carbonation.

2022-11 Applying ISO Standards to Geologic Storage and EOR Projects,

report managed by Samantha Neades

This study aimed to summarise and synthesise the two ISO Standards relevant to the geological storage of CO_2: – ISO 27914:2017 ('Carbon dioxide capture, transportation and geological storage - Geological storage') and ISO 27916:2019 ('Carbon dioxide capture, transportation and geological storage - Carbon dioxide storage using enhanced oil recovery (CO_2-EOR)') – to provide a high-level understanding of the content into an easily digestible format.

By comparison with international regulatory frameworks, and providing case studies of how applicable the standards are to real CO_2 storage projects, the study provides a comprehensive overview and concludes on the usefulness of the documents in supporting the implementation of CCUS projects.

The report concluded that:

- Both standards relevant to the geological storage of CO_2, ISO 27914 and ISO 27916, are complementary with minimal overlap, as was intended by stakeholders.
- ISO 27914 is intended for projects with the sole purpose of CO_2 storage:
- The objective being 'to commercial, safe, long-term containment of carbon dioxide in geological systems in a way that minimises risk to the environment, natural resources, and human health'.
- ISO 27916 is intended to apply to CO_2-EOR projects:
- With the objective of promoting 'the use of geologic storage associated with CO_2-EOR by providing a common process for assuring safe, long-term containment and for quantifying and documenting the amount of CO_2 that is stored in association with CO_2-EOR'.
- Both standards can be used to evaluate and guide key technical areas of storage projects, including site feasibility, well re-qualification and developing risk-based monitoring and verification programmes.
- Both standards provide limited specific support for requirements related to approval processes, ownership, government roles, subsurface ownership regime, and transport.
- Both standards support (in general) CO_2 stream definition, leakage accounting, MMV, storage and siting, closure, public engagement and risk assessments.
- Elements of ISO 27914 can provide guidance for CO_2-EOR projects, even though it is not explicitly intended for such use.
- There is a similarity between regulatory regimes for oil and gas projects and CO_2 storage projects and therefore existing petroleum regimes, complemented by the ISO standards, could be combined to form a specific regulatory regime for the geological storage of CO_2.
- Five examples are provided from developing economies with an oil and gas industry to show that regulations pertinent to CO_2 storage are either established or require refinement from pre-existing oil and gas regulations or need to be fully developed.
- The ISO standards are an evolving entity and subject to refinement and continuous updating where deemed necessary (ISO operate a 5-year review cycle on all published standards). Some experts have recognised that ISO standard 27914:2017 may be difficult to implement for real projects due to the large number of requirements, and suggest this standard could be seen as more of a best practice guide.

2022-TR01 Global Storage Capacity Workshop 2021, report managed by Samantha Neades

This workshop was a joint effort between the Clean Energy Ministerial (CEM) CCUS Initiative, the United States Department of Energy (DOE), the United States Geological Survey (USGS) and the IEA Greenhouse Gas R&D Programme (IEAGHG). Held on the 21st September 2021, this virtual workshop welcomed 59 invited attendees involved with and interested in CO_2 storage.

The aims of this workshop were to review current methodologies and initiatives for quantifying CO_2 geological storage, review current data availability and assess gaps, establish core international contacts and a community with direct interest in CO_2 storage resource. The workshop also discussed opportunities on how to address the identified data gaps in various parts of the world, through either bilateral or multilateral collaboration and via an international network to collate and refine estimates of CO_2 storage capacity.

2022-TR02 IEAGHG Risk Management Network – Webinar & Virtual Discussion: The Road to CCS Project Permitting, report managed by Samantha Neades

This webinar was organised by the IEAGHG Risk Management Network, which aims to bring worldwide experts together to discuss topics pertinent to the risk management of CCS / CCUS projects including risk analysis, risk data management, regulatory engagement and impacts of activities.

On Tuesday 18th January 2022, the IEAGHG Risk Management Network held a webinar which aimed to be a roundtable presentation of CCS / CCUS project operator experience, with risk management, during the permitting process. This webinar heard from panellists on the Northern Lights project, the Porthos project, California experiences with permitting and Oxy's recent project experiences. The webinar attracted an audience of 138 in addition to 8 panellists and 2 IEAGHG staff.

This webinar was an informal roundtable discussion to learn about the experiences that project operators have had relating to risk management during the permitting process. It provided an understanding of the challenges faced and explored potential ways to overcome such issues for future permits. The virtual event welcomed speakers from CCS projects and industry to hear their views and learn more about the challenges they have faced, specifically when going through the permitting process.

2022-TR03 Quantifying the socio-economic value of CCUS: a review, report managed by Keith Burnard

As policymakers consider options at their disposal to achieve the goals of the Paris Agreement, understanding the socio-economic impacts on local communities and industrial regions is crucial.

Integrated assessment models (IAMs), traditionally used to explore the feasibility of achieving climate targets and to inform global climate negotiations, often lack the economic, social and geographic detail to fully reveal the role that CCS and CDR technologies, such as BECCS, can play in national economies.

Three case studies are presented, each having previously been shared by the authors via published papers, conference presentations, workshops and seminars. They offer insights regarding the impacts of CCS and CDR deployment on regional economies and the relationship between industrial sectors and national strategic assets.

Case study 1 provides an illustration to show that the goal of maintaining employment in traditional industries and climate change mitigation can be aligned, contrary to the way it is often portrayed. Together with a commitment to a net-zero target, the employment opportunities that can arise from CCS deployment need to be carefully assessed.

Case study 2 demonstrates that, when pursuing net-zero targets in energy systems, there is no "one size fits all" solution, with the relative costs and opportunities associated with the energy transition unevenly distributed between sectors and countries. Hence, carbon mitigation strategies that simply focus on cost and neglect social, geopolitical and macro-economic considerations are likely to exacerbate labour market inequalities.

Case Study 3 shows that quantifying the socio-economic value of different BECCS pathways can inform policy makers of the optimal mix of CDR technologies to be deployed, while minimising biomass resource competition.

Ultimately, the case studies validate premises that decarbonisation strategies that neglect social, geopolitical, and macro-economic considerations, are likely to widen existing economic imbalances, both at regional and national levels. While CCS is widely acknowledged as essential to reach net-zero targets within economies, its deployment has faced numerous challenges. Recognising that the deployment of both CCS and BECCS has long continued to lag expectations, providing a multi-regional, technology agnostic and transparent quantification of the social value of these technologies may be the key to unlocking this impasse.

2022-TR04 CDR Workshop Bergen Norway 28 June 2022, report managed by Jasmin Kemper

Reports from the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA), have shown that Carbon Dioxide Removal (CDR) will be required to achieve net negative emissions to reach the target of the Paris Agreement, limiting the temperature increase caused by anthropogenic greenhouse gas (GHG) emissions to 1.5°C above pre-industrial levels.

On June 28, 2022, the Carbon Sequestration Leadership Forum Technical Group(CSLF TG), Clean Energy Ministerial (CEM) CCUS Initiative, IEAGHG, and the Mission Innovation (MI) CDR Mission jointly organized a workshop on CDR, hosted by the Research Council of Norway in Bergen, Norway.

The aim of the workshop was to provide members and other stakeholders with an update on the status of CDR, identify crucial knowledge gaps and the mechanisms to resolve them, and find possible cooperation/collaboration opportunities.

2022-TR05 5th International Workshop on Offshore Geologic CO_2 Storage, report managed by Samantha Neades

The 5th International Workshop on Offshore Geologic CO_2 Storage was held in New Orleans, Louisiana, USA on 19-20th May, 2022, a very appropriate location given the growing interest in, and vast potential for, offshore storage in the Gulf of Mexico.

With 50 attendees in-person and 120 virtually, there was a good mix of industry, researchers and regulators. In particular there was very good attendance by US regulators, State and Federal, as rule-making is underway at the Federal level to allow and regulate offshore CCS.

IEAGHG and Social Media

IEAGHG have a number of publications that are disseminated regularly to the Executive Committee and released into the public forum – including technical reports, technical reviews, information papers and one-off informative publications.

In 2022, 11 technical reports and 5 technical reviews were published (see page 20 for overviews or 34 for the list); two of these reports/reviews were on IEAGHG Network activity.

The IEAGHG Blog

https://ieaghg.org/ccs-resources/blog

The IEAGHG blog, live since December 2011, features both IEAGHG and external contributors, reporting on any and all IEAGHG activities – workshops, network meetings and conferences, promoting to its readers when a new technical report is published and also giving overviews of any significant external events that may be attended by us or our colleagues. The blog is still proving very popular! The Programme published 47 blogs during 2022.

Information Papers

https://ieaghg.org/ccs-resources/blog

In 2012, IEAGHG began producing and publishing Information Papers (IPs) as an additional communication tool. These continue to be extremely popular, both with IEAGHG Members and the public. The IPs are short summaries of new research developments in CCS, developments with other mitigation options and summaries of policy activities around the world on low carbon technology, and are an ideal way of satisfying the Programme's broader remit of reviewing all greenhouse gas mitigation options. If there are interesting developments from the IPs we would then undertake a technical review to understand better the issues and the political landscape, then if necessary, propose a detailed study to our members.

The majority of our IPs are free to access and are publicly available as soon as they are published. Occasionally, however, an IP will be deemed 'Confidential' or 'for the Executive Committee only' – in which case the document will not be available to download. We welcome Members and other external parties to submit relevant ideas to be made into an IP. IEAGHG published 14 IPs in 2022.

Social Media

https://twitter.com/IEAGHG
www.linkedin.com/company/1203238
https://www.facebook.com/IEAGHG/

The Programme's Twitter, LinkedIn and Facebook pages are thriving and being kept updated and current with regular posts on IEAGHG activities and other relevant news.

Since the publication of the 2021 Annual Review....

2416 Followers (6.4% increase)

facebook

1584 Likes (1.0% increase)

LinkedIn

1325 Group Members (10.8% increase)

IEAGHG Webinars

Webinars have now become a staple in our knowledge sharing cupboard. Each event is recorded and placed on our YouTube channel as an ongoing freely available resource. This year's offerings of webinars can be seen in Table 1 with the number of attendees and the number of YouTube views along with a brief description. Details of our webinars are sent out via our mailing list. If you do not receive our emails, please contact **timothy.wilson@ieaghg.org** or signup via http://eepurl.com/du7fkH to be included.

Webinar Title & Description	Date	No. Attendees	No. YouTube Views to Date
Criteria for Depleted Reservoirs to be Developed for CO_2 Storage Webinar This webinar looked at the IEAGHG study on Criteria for Depleted Reservoirs to be developed for CO_2 Storage, and included discussion with Alexander Bump, Susan Hovorka, Sahar Bakhshian (all BEG at Univerity of Texas at Austin) and Joshua Rhodes, Webber Energy Group at UT.	04/03/22	92	523
Study on Global Assessment of Direct Air Capture Costs Webinar This webinar included a discussion of IEAGHG Technical Report, 2021-05 Global Assessment of DACCS. Hosted by Jasmin Kemper, IEAGHG with Yourkcan Erbay, Element Energy.	23/03/22	78	264
Current State of Knowledge Regarding the Risk of Induced Seismicity at CO_2 Storage Projects Webinar A discussion of the IEAGHG Technical Report, 2022-02 Current State of Knowledge Regarding the Risk of Induced Seismicity at CO_2 Storage Projects. Hosted by James Craig, IEAGHG with Seyyed Hosseini, Sue Hovorka and Alexandros Savvaidis, all of BEG at Univerity of Texas at Austin.	13/04/22	134	145
Feasibility Study on Achieving Deep Decarbonization in Worldwide Fertilizer Production Webinar This webinar looked at IEAGHG Technical Report, 2022-05 Feasibility Study on Achieving Deep Decarbonization in Worldwide Fertilizer Production.	24/05/22	62	88
Low-carbon hydrogen from natural gas: Global roadmap Webinar A webinar to discuss the IEAGHG Technical Report, 2022-07 Low-carbon hydrogen from natural gas: Global roadmap.	23/08/22	63	307
Blue hydrogen: Beyond the plant gate Webinar A webinar to discuss the IEAGHG Technical Report, 2022-06 Blue hydrogen: Beyond the plant gate.	13/09/22	84	181
Quantifying the socio-economic value of CCUS: a review Webinar A webinar to discuss the IEAGHG Technical Review, 2022-TR03 Quantifying the socio-economic value of CCUS: a review.	09/11/22	*	105
Start-Up and Shutdown Protocol for Natural Gas-Fired Power Stations with CO_2 Capture Webinar A webinar to discuss the IEAGHG Technical Report: 2022-08 Start-Up and Shutdown Protocol for Natural Gas-Fired Power Stations with CO_2 Capture.	22/11/22	*	133
Summary highlights of COP27Webinar Arthur Lee of Chevron has attended many COPs and follows the negotiations inside UNFCCC closely, particularly on technology issues. He provided his insights on the developments and outcomes from COP27.	13/12/22	76	132

** Please note that due to a technical issue with our webinar provider, the attendee information for these webinars is unavailable.*

Table 1: List of 2022 Webinars

If there is a subject you would like to see presented, please send ideas and suggestions to Sam.Neades@ieaghg.org.

Technical Reports, Technical Reviews, Information Papers and Blogs

Report No.	Technical Report Title	Issue Date
2022-01	Criteria for Depleted Reservoirs to be Developed for CO_2 Storage	17/01/2022
2022-02	Current State of Knowledge Regarding the Risk of Induced Seismicity at CO_2 Storage Projects	01/02/2022
2022-03	Prime Solvent candidates for next generation of PCC plants	28/02/2022
2022-04	From CO_2 to Building Materials - Improving Process Efficiency	02/03/2022
2022-05	Feasibility study on achieving deep decarbonization in worldwide fertilizer production	03/03/2022
2022-06	Blue Hydrogen: Beyond the Plant Gate	03/08/2022
2022-07	Low-Carbon Hydrogen from Natural Gas Global Roadmap	03/08/2022
2022-08	Start-Up and Shutdown Protocol for Power Stations with CO_2 Capture	11/08/2022
2022-09	Defining the Value of Carbon Capture, Utilization and Storage for a Low-Carbon Future	11/08/2022
2022-10	Mineral Carbonation using Mine Tailings – A Strategic Overview of Potential and Opportunities	15/07/2022
2022-11	Applying ISO Standards to Geologic Storage and EOR Projects	27/09/2022

Table 2: List of 2022 Technical Reports

Review No.	Technical Review Title	Issue Date
2022-TR01	Global Storage Capacity Workshop 2021	18/02/2022
2022-TR02	IEAGHG Risk Management Network – Webinar & Virtual Discussion: The Road to CCS Project Permitting	31/03/2022
2022-TR03	Quantifying the Socio-Economic Value of CCS: A Review	03/08/22
2022-TR04	Carbon Dioxide Removal (CDR) Workshop, Bergen, Norway, 28th June 2022	05/08/22
2022-TR05	5th International Workshop on Offshore Geologic CO_2 Storage	17/10/2022

Table 3: List of 2022 Technical Reviews

IP No.	Information Paper Title	Author	Issue Date
2022-IP01	OGCI Gulf Countries CCUS White Paper External Stakeholder Workshop	JC	31/01/2022
2022-IP02	IPCC Climate Change 2022: Impacts, Adaptation and Vulnerability	JK	10/03/2022
2022-IP03	IPCC approves the Summary for Policymakers for Working Group III Mitigation of Climate Change	AL	13/04/2022
2022-IP04	CONFIDENTIAL	JC	13/04/2022
2022-IP05	IPCC Climate Change 2022: Mitigation of Climate Change	JK	04/05/2022
2022-IP06	BEIS review for next generation carbon capture technology	AA	07/07/2022
2022-IP07	CONFIDENTIAL	TD	11/07/2022
2022-IP08	ETC Report on the role of CCUS in the Energy Transition	KB	20/07/2022
2022-IP09	2nd NET Conference	JK	01/08/2022
2022-IP10	Carbon Management Project Review Meeting - Part I	NC	29/09/2022
2022-IP11	Carbon Management Project Review Meeting - Part II	NC	29/09/2022
2022-IP12	World Energy Outlook 2022	KB	22/11/2022
2022-IP13	ECR conference	AA	13/12/2022
2022-IP14	CONFIDENTIAL	JK	14/12/2022

Table 4: List of 2022 Information Papers

Staff Abbreviations:
AA: Abdul'Aziz Aliyu
AL: Arthur Lee
JC: James Craig
JK: Jasmin Kemper
KB: Keith Burnard
NC: Nicola Clarke
TD: Tim Dixon

Blog Title	Author	Issue Date
New IEAGHG Technical Report: Criteria for Depleted Reservoirs to be Developed for CO_2 Storage	SN	17/01/2022
New IEAGHG report: Global Assessment of DACCS Costs, Scale and Potential	JK	28/01/2022
UTCCS-6 – Texas hotspot for CCUS	TD	31/01/2022
New IEAGHG Report: Current State of Knowledge Regarding the Risk of Induced Seismicity at CO_2 Storage Projects	JC	01/02/2022
New IEAGHG report: Assessing the Techno-Economic Performance, Opportunities and Challenges of Mature and Nearly-mature Negative Emissions Technologies (NETs)	JK	02/02/2022
New IEAGHG Technical Report: Prime Solvent candidates for next generation of post-combustion CO_2 capture plants	AA	28/02/2022
New IEAGHG report: From CO_2 to Building Materials – Improving Process Efficiency	SN	02/03/2022
IEA flagship report "Global Energy Review: CO_2 Emissions in 2021"	JK	11/03/2022
Energy emission challenges from COVID and conflict - Do not forget CCS works on coal power also	TD	16/03/2022
March 2022 Issue of Greenhouse News now available	TB	31/03/2022
"Our Climate is our Future. Our Future is in our Hands". IPCC Report on Mitigation of Climate Change	TD	05/04/2022
Welcome return of in person events as IEAGHG ExCo meeting is hosted in Sardinia	TB	16/05/2022
5th International Workshop on Offshore Geologic CO_2 Storage	TD	23/05/2022
OPEC's 4th Workshop on Energy Technology	JC	23/05/2022
2nd International Negative CO_2 Emissions Conference, Chalmers University of Technology, Sweden June 14-17, 2022	JK	15/06/2022
2nd International Negative CO_2 Emissions Conference: An Overview of the DAC Technology field – Keynote by Mijndert van der Spek, Heriot-Watt University	JC	1/7/06/2022
Key Accomplishments at SB56, Bonn, Germany	AL (Arthur Lee)	21/06/2022
CCS history in the making - CSLF visit to the Northern Lights Receiving Terminal at Oygarden	TD	04/07/2022
New IEAGHG Technical Report: 2022-10 Mineral Carbonation using Mine Tailings – A Strategic Overview of Potential and Opportunities	JC	15/07/2022
New Supervisory Body for Paris Agreement Article 6.4 mechanism considers Removals	TD	01/08/2022
New IEAGHG Technical Report: 2022-06 Blue Hydrogen Beyond the Plant Gate	AA	02/08/2022
New IEAGHG Technical Report: 2022-07 Low Carbon Hydrogen from Natural Gas: Global Roadmap	AA	03/08/2022
New IEAGHG report: 2022-08 Start-Up and Shutdown Protocol for Power Stations with CO_2 Capture	KB	11/08/2022
New IEAGHG Technical Report: 2022-09 Defining the Value of Carbon Capture, Utilization and Storage for a Low-Carbon Future	KB	11/08/2022
New beginnings for carbon capture with Section 45Q tax credits in the United States	RE (Richard Esposito)	12/08/2022

Table 5: List of 2022 Blogs

Blog Title	Author	Issue Date
NETL 2022 Carbon Management Project Review Meeting, Pittsburgh – Open Plenary (Monday 15th August)	NC	17/08/2022
World's First Commercial Pact on Cross-Border CO_2 Transport and Storage	AA	05/09/2022
IEEFA report critical of CCS - but it presents a misleading picture	JC	08/09/2022
Global Clean Energy Action Forum (GCEAF) in Pittsburgh	TD	26/09/2022
New IEAGHG Technical Report: 2022-11 Applying ISO Standards to Geologic Storage and EOR Projects	SN	27/09/2022
GHGT-16: Opening Plenary	SN	24/10/2022
GHGT-16: Day 2 Technical Plenary: TotalEnergies & US DOE	NC	25/10/2022
GHGT-16: Session 4B, Depleted Reservoirs & Injectivity	SN	25/10/2022
GHGT-16: Session 5B, Storage Costs	SN	25/10/2022
GHGT-16: Panel 6C on 'Upstream emissions and the limits to emissions reductions from CCS'	JK	26/10/2022
GHGT-16: Final panel session and GHGT-17 announcement	AA	02/11/2022
GHGT-16: Commercialising CCUS in the Middle East: Gulf region and Egyptian hub study cases	SN	03/11/2022
GHGT-16 Panel Discussion 5C: CO_2 impurities and implications for multiple source networks and hubs	AA	03/11/2022
GHGT-16: Panel Discussion 8C: Repurposing existing infrastructure	NC	04/11/2022
GHGT-16 site visit to Limagne D'Allier Basin 'Natural CO_2 release' - 28th October 2022	NC	04/11/2022
GHGT-16 site visits to IFP Energies Nouvelles (IFPEN) and Cimentalgue Project	AA	04/11/2022
COP27 starts in Egypt	TD	08/11/2022
Half-way update from COP27	TD	14/11/2022
GHGT-16 Technical Plenary 2, Wednesday 26th October 2022	JC	15/11/2022
GHGT-16 Technical Plenary 3 Thursday 27th October 2022	JC	15/11/2022
Final Blog from COP27 – Expectations and Outcomes	TD	21/11/2022
14th IEAGHG International Summer School	SN	07/12/2022

Table 5 (continued): List of 2022 Blogs

Staff Abbreviations:
AA: Abdul'Aziz Aliyu
JC: James Craig
JK: Jasmin Kemper
KB: Keith Burnard
NC: Nikki Clarke
SN: Samantha Neades
TB: Tom Billcliff
TD: Tim Dixon

IEAGHG Presentations Made in 2022

Date	Meeting Title	Presentation Title	Speaker
18/01/2022	CCSA Webinar	COP26 Update	Tim Dixon
23/01/2022	UTCCS6, Austin	COP26 Outcomes for CCUS	Tim Dixon
01/02/2022	GECF Webinar	COP26 Outcomes for CCUS	Tim Dixon
15/02/2022	GCCA Webinar	COP26 Outcomes for CCUS	Tim Dixon
23/02/2022	Special Seminar Series (U Regina)	CCUS in the Global Climate Scene	Tim Dixon
16/03/2022	Virtual Seminar - Prospects of Carbon Capture and Storage for Guyana	CCS in the Global Climate Scene	Tim Dixon
22/03/2022	OPEC Lecture	The Role of CCUS in Reducing GHG Emissions in the Oil Industry	James Craig
13/04/2022	Making CCS/CCUS Affordable: Enabling CCUS Deployment in G20 and Beyond: Indonesia G20 Workshop	What Developing Countries can do to Implement CCUS	Tim Dixon
22/04/2022	BEG Seminar	COP26 and Outcomes for CCUS	Tim Dixon
22/08/2022	NETL Carbon Management Meeting	Update and International Perspectives from IEAGHG	Tim Dixon
15/11/2022	Capacity Building Workshop: Role of Carbon Capture, Storage and Utilization in Decarbonization, Dhaka, Bangladesh	Future Role of CCS Technologies in the Power Sector	Keith Burnard
07/12/2022	IEA Working Party on Fossil Energy 85th Meeting	Update from GHG TCP (IEAGHG)	Tim Dixon

Table 6: List of 2022 Presentations (in addition to those in our own meetings)

Members of the Programme

AUSTRALIA
Dr Paul Feron (M)
Dr Kelly Thambimuthu (Chairman)

AUSTRIA
Mr Theodor Zillner (M)
Dr Gunter Simader (A)

CANADA
Dr Eddy Chui (M)

EUROPEAN COMISSION
Dr Vassilios Kougionas (M)
Mr Jeroen Schuppers (A)

FINLAND
Jussi Mäkelä (M)
Francesco Reda (A)
Elke Schnabel(A)

FRANCE
Isabelle Czernichowski (M)
Alix Bouxin (A)

INDIA
Dr Atul Kumar (M)

JAPAN
Dr. Ziqui Xue (A)
Dr. Tomonari Minezaki (A)

KOREA
Jeom-In Baek (M)

NEW ZEALAND
Mr John Burnell (M)
Mr Mark Pickup (A)

NETHERLANDS
Gerdi Breembroek (M)
Martijn van de Sande (A)

NORWAY
Dr Åse Slagtern (M & VC)
Mr Hans Jørgen Vinje (A)

OPEC
Dr. Abderrezak Benyoucef (M)
Ms Angelika Hauser (A)
Dr. Eleni Kaditi (A)

SOUTH AFRICA
David Khoza (M)
Mr Thulani Maupa (A)

SWEDEN
Svante Soderholm (M)
Isabella Gustafsson Ismodes (A)

SWITZERLAND
Valentin Gischig (M)
Dr Sophie Wenger (A)

UNITED KINGDOM
Mr Will Lochead (M)
Carly Leighton (A)

USA
Mr Mark Ackiewicz (M & VC)
Anhar Karimjee (M)
John Litynski (A)
Jeff Hoffman (A)

Baker Hughes
Dr. Alex Cruz (M)
Ms Allyson Anderson Book (A)

bp
Martin Towns (M)
Simon Shoulders (A)

Mr Arthur Lee (M)

CIAB
Peter Morris (M)
Mr Mick Buffier (A)
Karl Bindermann (A)

drax
Dr Catriona Reynolds (M)

eni
Guido D'Alfonso (M)
Sonia Caprara (A)
Salvatore Gimmett (A)

EPRI
Mr Robert Trautz (M)

equinor
Jamie Andrews (M)
Peter Zweigel (A)

Mr Ganesh Dasari (M)

Heiko Gerhauser (M)
Eric Busche (A)

Dr. Antonia Diego Marin (A)

Prof Dr. Warwan Gunawan A Kidir (M)
Dr. Mohammad Rachmat Sule (A)

Mr Atsushi Matsumoto (M)
Mr Tsukasa Kumagai (A)

Seiji Hongo (M)
Shinichi Sakuno (A)

Tilman Bechtold (A)
Karl-Josef Wolf (M)

Dr. Owain Tucker (M)

Gianni Serra (M)

Richard Esposito (M)

Philip Llewellyn (M)

Sara Budinis

Evaluating technology options to mitigate greenhouse gas emissions

IEA Greenhouse Gas R&D Programme

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