Carbon Sequestration Leadership Forum
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Minutes of the Technical Group Meeting
Champaign, Illinois, U.S.A.
Thursday-Friday, 25-26 April 2019

LIST OF ATTENDEES

Chair Åse Slagtern (Norway)

Delegates

Australia:	Martine Woolf (*Vice Chair*), Max Watson
Canada:	Eddy Chui (*Vice Chair*), Mike Monea
China:	Xian Zhang, Shihan Zhang
European Commission:	Jeroen Schuppers
Japan:	Ryozo Tanaka (*Vice Chair*)
Netherlands:	Harry Schreurs
Norway:	Lars Ingolf Eide, Espen Bernhard Kjærgård
Saudi Arabia:	Ahmed Aleidan, Hamoud AlOtaibi, Pieter Smeets
South Africa:	Thulani Maupa
United Kingdom:	Brian Allison
United States:	Mark Ackiewicz, Sallie Greenberg

Representatives of Allied Organizations

CO_2GeoNet Association:	Ceri Vincent
Global CCS Institute:	Robert Mitchell
IEAGHG:	Tim Dixon

CSLF Secretariat Richard Lynch

Invited Speakers

United Kingdom:	Jon Gibbins *(U.K. CCS Research Centre / University of Sheffield)*
United States:	Richard Berg *(Illinois State Geological Survey / University of Illinois)*
	Adam Goff *(8 Rivers / NET Power)*
	Neeraj Gupta *(Battelle)*
	Susan Hovorka *(University of Texas / Bureau of Economic Geology)*
	Grant Bromhal *(Department of Energy / National Energy Technology Laboratory)*
	Greg Kennedy *(NRG Energy / Petra Nova Project)*
	Jan Steckel *(Department of Energy / National Energy Technology Laboratory)*
	Neil Wildgust *(University of North Dakota / Energy & Environmental Research Center)*
	Frank Morton *(National Carbon Capture Center)*

Observers

China:	Xi Liang *(U.K.-China CCUS Center – Guangdong)*
Chinese Taipei:	Meng-Chun Chang *(Taiwan Power Company)*
	Chung-Hsien Chen *(Bureau of Enerrgy)*
	Young Ku *(Taiwan Research Institute)*
	Chi-Wen Liao *(Industrial Technology Research Institute)*
	Jiing-Yong Lin *(Taiwan Power Company)*
	Yu-Ying Lu *(Bureau of Enerrgy)*
	Hou-Ping Wan *(Industrial Technology Research Institute)*
Japan:	Jiro Tanaka *(Japan CCS Company)*
Norway:	Kari-Lise Rørvik *(Gassnova)*
Trinidad and Tobago:	Andrew Jupiter *(University of the West Indies)*
United Kingdom:	Diane Barnett *(Private Researcher for PACT / University of Sheffield)*
United States	Keri Canaday *(Illinois State Geological Survey / University of Illinois)*
	Ganesh Dasari *(ExxonMobil)*
	Randy Locke *(Illinois State Geological Survey / University of Illinois)*
	Yongqi Lu *(Illinois State Geological Survey / University of Illinois)*
	Kevin McCabe *(Department of Energy / National Renewable Energy Laboratory)*
	Jeffrey McDonald *(Consultant for Wabash Valley Resources)*
	Taka Misumi *(Petra Nova Project)*
	Katherine Romanak *(University of Texas / Bureau of Economic Geology)*
	Ashleigh Ross *(BP)*
	Robert Van Voorhees *(Carbon Sequestration Council)*
	Chris Walker *(BP)*

Thursday Session

1. Welcome and Opening Remarks

The Chair of the Technical Group, Åse Slagtern, called the meeting to order, welcomed CSLF delegates and stakeholders to Champaign, and introduced the new PIRT Chair, Martine Woolf of Geoscience Australia. Ms. Slagtern mentioned that this would be a busy meeting, with presentations on many topics of interest related to carbon capture and storage (CCS) including presentations by the International Test Center Network, the Mission Innovation Carbon Capture Challenge, several United States-based projects and initiatives including an overview of United States Department of Energy-sponsored CCS activities, and five CSLF-recognized projects. Additionally, there would be updates from all of the Technical Group's task forces as well as the Technical Group's three allied organizations: the CO_2GeoNet Association, the Global CCS Institute (GCCSI), and the IEA Greenhouse Gas R&D Programme (IEAGHG). Ms. Slagtern also called attention to the downloadable documents book that had been prepared by the Secretariat for this meeting which contains documents relevant to items on the agenda.

2. Meeting Host's Welcome

Richard Berg, Director of the Illinois State Geological Survey, welcomed meeting attendees to Champaign. Dr. Berg stated that the Illinois State Geological Survey is part of the Prairie Research Institute, which also includes the Illinois Sustainable Technology Center and other state surveys in the areas of water resources, natural history, and archeology. In all, the Prairie Research Institute has approximately 900 scientists and

support staff and has been addressing critical scientific and societal issues for many decades, particularly in Illinois but also nationally and internationally. Dr. Berg concluded his remarks by stating that he was pleased that the CSLF has come to Illinois for its mid-year Technical Group meeting and hoped that the information exchange from the meeting would be rewarding and productive to all.

3. Introduction of Delegates

Technical Group delegates and stakeholders present for the meeting introduced themselves. Eleven of the twenty-six CSLF Members were represented. Stakeholder observers from nine countries were also present, as were representatives from the three allied organizations.

4. Adoption of Agenda

The Agenda was adopted with no changes.

5. Approval of Minutes from October 2018 Meeting

The Minutes from the October 2018 Technical Group Meeting were approved with no changes.

6. Report from CSLF Secretariat

Richard Lynch provided a report from the CSLF Secretariat which reviewed highlights from the October 2018 CSLF Annual Meeting in Melbourne, Australia. This was a four-day event, consisting of PIRT, Technical Group, and Policy Group meetings, as well as a site visit to the CO2CRC Otway Project. Presentations from all meetings are online at the CSLF website.

Mr. Lynch reported that there were several notable highlights and outcomes from the Annual Meeting:

- The CO_2 Field Lab Project, sited in Norway, received a CSLF Global Achievement Award. (*Note: The project sponsor representative was not able to attend the meeting, so presentation of the award took place the following week.*)
- Enabling Onshore CO_2 Storage in Europe (ENOS) became a CSLF-recognized Project.
- Norway was re-elected as Technical Group Chair. Australia and Canada were re-elected as Technical Group Vice Chairs. Japan was also elected as Technical Group Vice Chair, replacing South Africa.
- The CSLF will no longer hold combined Annual Meetings of the Policy Group and Technical Group. The Technical Group will still meet twice each year while Policy Group meetings will be separate events, the next one being held in conjunction with the Clean Energy Ministerial (CEM) meeting at the end of May in Canada.
- The Technical Group formed a new Task Force on Hubs and Infrastructure to conduct initial "Phase 0" activities. This would consist of reviewing activities and presentations/reports since publication of the CSLF Technology Roadmap (TRM) in 2017, and the task force would make a recommendation at the 2019 Technical Group Mid-Year Meeting on whether or not to continue past the preliminary phase. Task force members include the Norway (Chair), Australia, Brazil, Canada, and the United Kingdom.

- The CCS for Energy Intensive Industries Task Force, chaired by France, and the Improved Pore Space Utilisation Task Force, co-chaired by Australia and the United Kingdom, will both present final reports at the next Technical Group meeting.
- The Non-EHR Utilization Options Task Force will present an interim report with a set of recommendations at the 2019 Technical Group Mid-Year Meeting.
- The Technical Group's Ad Hoc Committee for Task Force Maximization and Knowledge Sharing will continue its activities for the foreseeable future. The Technical Group will provide specific direction and purpose.
- A general working mode going forward for collaborating with allied organizations will be to jointly produce overview reports, hold workshops, and engage in other similar activities. The Ad Hoc Committee will work out practical implementation.
- The International Test Center Network will provide the Technical Group a list of specific recurring challenges that need to be addressed for specific CO_2 capture technologies.
- The IEAGHG and Norway's Technical Group delegation will plan a joint CSLF-IEAGHG workshop themed on Hydrogen with CCS.

Mr. Lynch concluded his presentation by reviewing the general status of the CSLF-recognized projects, which are locate on five different continents. As of April 2019, there are 55 recognized projects, 32 of which are active and another 23 which have been completed. No projects were proposed for CSLF recognition at the current meeting.

7. Update from the CO_2GeoNet Association

Ceri Vincent, President of the CO_2GeoNet Association, gave a short presentation about the organization and its activities. CO_2GeoNet is a pan-European research association for advancing geological storage of CO_2. It was created as a European Union FP6 Network of Excellence in 2004 and transformed into an Association under French law in 2008. Ms. Vincent stated that the overall mission of the CO_2GeoNet Association is to be the independent scientific voice of Europe on CO_2 geologic storage in order to build trust in the technologies involved and to support wide-scale CCS implementation. Membership comprises 30 research institutes from 21 countries, and CO_2GeoNet uses the multidisciplinary expertise of its members to advance the science supporting CCS. There are currently four categories of activities: joint research, scientific advice, training, and knowledge sharing. The CO_2GeoNet Association is also overseeing the ongoing ENOS project, whose objective is to provide crucial advances which will help foster onshore geologic CO_2 storage in Europe.

Ms. Vincent concluded her presentation by providing information on some upcoming actions of the organization. These include training and capacity building at the ENOS Spring School and the Sulcis Summer School, communication and knowledge sharing activities at the upcoming 11th World Conference of Science Journalists in Switzerland and at COP25 in Chile. CO_2GeoNet is also providing scientific advice to the ISO in development of standards relevant to CCUS and to the ZEP Implementation Working Group in its efforts to demonstrate CCS in the European Union. Ms. Vincent stated that the next Open Forum will be held in Venice on May 7-8 with workshops on May 9, and that she hoped that many CSLF delegates would be able to attend.

8. Update from the IEA Greenhouse Gas R&D Programme (IEAGHG)

Tim Dixon, Programme Manager for the IEAGHG, gave a presentation about the organization and its continuing collaboration with the CSLF's Technical Group. The IEAGHG was founded in 1991 as an independent technical organization with the mission to provide information about the role of technology in reducing greenhouse gas emissions from use of fossil fuels. Currently there are 34 members from 15 countries plus OPEC, the European Union, and the IEA's Coal Industry Advisory Board (CIAB). These members set the strategic direction and technical programme for the organization. The IEAGHG's focus is on CCS, and the goal of the organization is to produce information that is objective, trustworthy, and independent, while also being policy relevant but not policy prescriptive. The 'flagship' activities of the IEAGHG are the technical studies and reports it publishes on all aspects of CCS (more than 330 reports published on all aspects of CCS), the six international research networks about various topics related to CCS, and the biennial GHGT conferences (the most recent in Melbourne, Australia the week following the 2018 CSLF Annual Meeting). Other IEAGHG activities include its biennial post-combustion capture conferences (the next in September 2019 in Kyoto, Japan), its annual International CCS Summer School (the next in July 2019 in Regina, Canada), peer reviews with other organizations, activity in international regulatory organizations (such as the UNFCCC, the ISO TC265, and the London Convention), and collaboration with other organizations (including the CSLF). The IEAGHG has also held CCS side events at the past five COPs. The COP24 side event was titled "Can CCS decarbonize industry in developed and developing countries?" and had 150 attendees.

Mr. Dixon mentioned that since 2008 the IEAGHG and CSLF Technical Group have enjoyed a mutually beneficial relationship which allows each organization to cooperatively participate in the other's activities. This has included mutual representation of each at CSLF Technical Group and IEAGHG Executive Committee (ExCo) meetings, and also the opportunity for the Technical Group to propose studies to be undertaken by the IEAGHG. These, along with proposals from IEAGHG ExCo members, go through a selection process at semiannual ExCo meetings. So far there have been seven IEAGHG studies that originated from the CSLF Technical Group or related activities, including reports on three International Workshops on Offshore Geologic CO_2 Storage.

Mr. Dixon concluded his presentation by showing lists of reports recently published, reports in progress to be published, studies underway, studies awaiting start, and webinar series. Mr. Dixon also briefly described IEAGHG's research networks and other upcoming events.

9. Update from the Global CCS Institute

Robert Mitchell, Senior Client Engagement Lead for the Global Carbon Capture and Storage Institute (GCCSI), gave a short presentation about the organization. The GCCSI has an overall mission of accelerating the deployment and commercial viability of CCS globally. Mr. Mitchell mentioned that services of the GCCSI include research on key aspects of CCS deployment (including publication of an annual "Global Status of CCS" document), advice and capacity building (through tailored workshops, conferences, and presentations to groups such as the CSLF), and communications / advocacy (to build awareness of CCS and its role in achieving climate targets and reducing emissions).

One of the slides in Mr. Mitchell's presentation summarized the global status of carbon capture deployment. As of December 2018 there were 43 large-scale facilities which cumulatively capture 94 million metric tons per year of CO_2, with another 23 facilities

under construction which will capture about an additional 40 million metric tons per year. Besides these, there are 20 facilities in various stages of development which, together, will capture about 54 million metric tons per year. Cumulatively, all of these facilities' CO_2 capture capabilities total to less than half of the 2025 target, as called out in the 2017 TRM, of 400 million metric tons of CO_2 captured and stored.

Mr. Mitchell concluded his presentation by listing some important learnings that have resulted from these GCCSI activities. They include the realization that CCS is currently too expensive and that there needs to be some indication on how much and how quickly CCS costs will come down. Collaborative activities are the key to success, and the focus should be on value. And, as we are all too aware, the time to act is now.

10. Update on the Mission Innovation Carbon Capture Challenge

Brian Allison, Assistant Head CCUS R&D and Innovation at the United Kingdom's Department for Business, Energy and Industrial Strategy and Co-Lead (with Saudi Arabia and Mexico) for Mission Innovation's Carbon Capture Challenge (CCC), gave a short update about Mission Innovation and its CCC. Mission Innovation is a multilateral Ministerial-level initiative that was launched in November 2015 with the overall goal of accelerating the pace of clean energy innovation, to achieve performance breakthroughs and cost reductions in order to provide widely affordable and reliable clean energy solutions. Mission Innovation seeks to double cumulative Mission Innovation countries' research, development and demonstration (RD&D) investment in clean energy (from US$15 billion to US$30 billion) over five years (from 2016 to 2021), to increase private sector engagement in clean energy innovation, and to improve information sharing among Mission Innovation countries.

Mr. Allison stated that currently there are twenty Mission Innovation countries plus the European Commission that are participating in the CCC. The overall objective is to enable near-zero CO_2 emissions from power plants and carbon intensive industries. This would involve identifying and prioritizing breakthrough CCUS technologies, developing pathways to close RD&D gaps, recommending multilateral collaboration mechanisms, and driving down the cost of CCUS through innovation. The overall work plan includes organizing CCUS Experts Workshops, engaging stakeholders (both industry and NGOs), and building multilateral collaboration mechanisms. To that end, a Mission Innovation workshop will be held in Trondheim, Norway, following the conclusion of the June 2019 Trondheim CCS Conference. This workshop will be a successor to an earlier workshop, held in Houston, U.S.A. in 2017 which had focused on early stage research in CCUS. The Trondheim workshop is intended to build on and continue the work from the Houston workshop towards implementation and commercialization of CCUS technologies.

Mr. Allison also stated that Mission Innovation is organizing a one-hour roundtable event for the upcoming Mission Innovation Ministerial, which will take place in late May in Vancouver, Canada. This will be an invitation-only event, as there are only twelve seats (for Ministers and senior industry figures) around the table, with dual focuses on CCUS and hydrogen.

Mr. Allison ended his presentation with a short update about the Accelerating CCS Technologies (ACT) initiative. The first ACT call for project proposals was published in 2016 and resulted in eight projects. A second ACT call was published in June 2018, with a budget of approximately €30 million, and resulted in 26 project proposals currently being evaluated, many of which address Mission Innovation's CCC. Mr. Allison stated that this had been expected, as that second call had specifically included a request for

project proposers to address priority research directions (PRDs) that were identified at the Houston Mission Innovation workshop. *(Note: The report from the Houston workshop and the "Mission Innovation: Priority Research Directions Survey" is online at the U.K. CCS Research Centre website: https://ukccsrc.ac.uk/mission-innovation-priority-research-directions-survey)*

11. Report from the CSLF Projects Interaction and Review Team (PIRT)

Technical Group Chair Åse Slagtern prefaced this agenda item by stating that due to time constraints and because there were no new projects to be evaluated for CSLF recognition, there had been an agreement by the Technical Group's Executive Committee to forgo the PIRT meeting this time and instead incorporate any PIRT business into the Technical Group meeting.

The PIRT Chair, Martine Woolf, asked for comments on the draft Summary from the October 2018 PIRT meeting. Hearing none, she declared the Meeting Summary as final. Dr. Woolf then briefly reviewed the status of one of the PIRT's most important activities: engagement of CSLF-recognized projects. A survey that obtained information from 25 of 35 active CSLF-recognized projects was conducted prior to the CSLF's 2017 Mid-Year meeting, using the following format developed by the PIRT for project sponsors to inform the CSLF of their status:

One of the outcomes from the survey was that the form needed revision to include questions to project sponsors on why they sought CSLF recognition for their projects, and what benefits have there been (or are expected) from CSLF recognition. Additionally, there were recommendations that the PIRT or Technical Group should determine what if anything that the CSLF can offer to projects that become recognized by the organization and, even more importantly, what the CSLF wants to achieve by recognizing projects. To that end, Dr. Woolf asked for comments on the survey: how it should be enhanced and improved. There were no immediate suggestions from any delegate, so in the interest of time this item was tabled and the Secretariat was asked to send out an email to delegates asking for comments with a deadline of receiving them no later than the 24th of May.

Dr. Woolf then asked Sallie Greenberg to lead the discussion about how the PIRT should function going forward, with emphasis on defining PIRT membership and if it should continue to hold it meetings prior to Technical Group meetings. There was spirited discussion from many delegates, including Mark Ackiewicz, Ahmed Aleidan,

Lars Ingolf Eide, Harry Schreurs, Pieter Smeets, Max Watson, and Xian Zhang. Some of the suggestions put forth were to:

- Limit PIRT membership to only a few delegates, with the understanding that PIRT delegates will be expected to be greatly participatory in its project review and project engagement activities.
- Have only one presentation from sponsors of projects proposed for CSLF recognition. These would occur during PIRT meetings, with the PIRT Chair presenting a summary to the Technical Group during its meetings.
- Avoid making the PIRT into a Technical Group "committee of the whole". Keep the PIRT as an institution but reshape it. For instance, much of the PIRT's business could possibly be conducted via email or by teleconferences. Only convene PIRT meetings during times when projects have been proposed for CSLF recognition.
- Allow PIRT decisions concerning project recognition and other matters to stand unless expressly overridden by the Technical Group.
- Allow the PIRT to have a role in determining which projects give presentations during Technical Group meetings. *(Note: Currently, the CSLF Secretariat has this role, with oversight from the Technical Group's Executive Committee which reviews and approves the agendas for Technical Group meetings.)*
- Give the PIRT prime responsibility to recruit projects for CSLF recognition.
- Find new activities for the PIRT which are in accordance with its mandate (as described in the PIRT Terms of Reference). Update the PIRT Terms of Reference as necessary to keep up with the PIRT's functions as they evolve going forward.

Dr. Woolf thanked everyone for their suggestions and stated that she would develop a proposal on how the PIRT will function going forward.

12. Update from the CSLF Policy Group

Mark Ackiewicz, on behalf of the CSLF Policy Group Chair, gave a short presentation which provided outcomes and action items from the October 2018 Policy Group meeting in Melbourne. These included:

- The United States was re-elected as Policy Group Chair. China, Saudi Arabia, and the United Kingdom were re-elected as Policy Group Vice Chairs.
- The CSLF will no longer hold combined Annual Meetings of the Policy Group and Technical Group. The Technical Group will still meet twice each year and near term, Policy Group meetings will be co-branded with CEM meetings with the next one being held in conjunction with the CEM meeting at the end of May in Vancouver, Canada.
- The Policy Group approved the ENOS initiative as a CSLF-recognized project.
- The "International Roundtable on Strengthening Collaboration on CCUS", hosted by Japan in February 2019 in Washington, D.C., U.S.A., was held in cooperation with the CSLF.
- The Capacity Building Governing Council will work to transfer all remaining funds toward supporting similar work through the CEM CCUS Initiative, and then dissolve the CSLF Capacity Building Program.
- The Communications Task Force will explore new communications alignment with CSLF stakeholder representatives and others. It will also facilitate more

CSLF regional stakeholder meetings while targeting other audience members (in coordination with CSLF stakeholders), and will work to carry core CSLF messages under the CEM CCUS Initiative (in coordination with the CEM).

- All CSLF delegations were requested to provide updated country developments to the CSLF Secretariat for CSLF website pages.

Mr. Ackiewicz also provided a short update on the CEM CCUS Initiative, which is currently comprised of ten member governments: Norway, Saudi Arabia, the United States, and the United Kingdom as lead countries, and Canada, China, Japan, Mexico, South Africa, and the United Arab Emirates as participating CEM members. In addition, there are currently two observer governments (the European Commission and the Netherlands) and several allied organizations (including the CSLF). Industry (including the oil and gas community) and financial institutions (including multilateral development banks) are also involved. Key objectives of the CCUS Initiative include:

- Expanding the spectrum of clean energy technologies actively considered under CEM to include CCUS;
- Creating a sustained platform for the private sector, governments and the investment community to engage and accelerate CCUS deployment;
- Facilitating identification of both near and longer-term investment opportunities to improve the business case for CCUS; and
- Disseminating emerging CCUS policy, regulatory and investment best practices as part of integrated clean energy systems.

Mr. Ackiewicz stated that at the upcoming CEM meeting, the CCUS Initiative hoped to achieve the following:

- True engagement with several financial sector players;
- Significant knowledge-sharing on CCUS experience via webinars;
- Greater awareness of the CCUS Initiative among CEM countries, industries, key organizations, and the financial sector; and
- Progress in moving forward with plans for the CCUS Initiative to take over CSLF Policy Group activities.

Mr. Ackiewicz closed the Policy Group's presentation by stating that the upcoming CEM meeting would include a CCUS Focus event titled "Accelerating CCUS Together – Financing a Key Piece of the Clean Energy Puzzle". This is being structured around three main themes (business models for CCUS, public policy and regulatory frameworks, and increasing investment in CCUS) with participants expected to include Ministers, finance sector executives, and industry CEOs.

Two questions arose during the ensuing discussion. Tim Dixon inquired that once the CSLF Capacity Building funds are moved to the CEM CCUS Initiative, would they still be accessible to assist CSLF developing country members and for similar activities? At the previous CSLF meeting, there had been a suggestion to utilize these funds as assistance to non-CSLF developing countries as a means of encouraging them to join the CSLF and/or participate in CSLF-branded events. Ceri Vincent asked for further information about the status of the CSLF's stakeholder engagement initiative beyond what was shown in the presentation. Mr. Ackiewicz replied that he would pass these inquiries on to the Policy Group.

13. Report from the CCUS for Energy Intensive Industries Task Force

Task Force Co-Chair Dominique Copin was unable to attend the meeting, so he gave his presentation via a telephone link-up that was facilitated by Lars Ingolf Eide. The task force had been established at the October 2016 meeting in Tokyo with a mandate to investigate the opportunities and issues for CCUS in the industrial sector and show what the role of CCUS could be as a lower-carbon strategy for CO_2-emitting industries. The focus of the task force is to show how CCUS in Energy Intensive Industries (EIIs) will contribute to the double target of economic growth and climate change mitigation, with an objective to provide recommendations for technology developments that are needed to accelerate the deployment of CCUS for these industries.

Mr. Copin stated that the task force had not quite completed its final report, but that it was far enough along that he could present some of its findings and conclusions. These include:

- EIIs are the key building blocks of all economies, and their cumulative share of CO_2 emissions is significant. However, some EIIs will play a significant role in decarbonizing other industries (such as hydrogen for the steel industry).
- EIIs are actively working on decreasing their CO_2 emissions through use of energy efficient technology, process improvements, and utilization of new sources of energy. However, wide-scale CO_2 utilization will be necessary for EIIs to achieve net zero emissions.
- The development of CCUS in EIIs will require commitment from various players, including governments, the oil and gas sector, end use consumers, CCUS organizations, and the EIIs themselves. Each of these players has its own set of mandates and challenges to overcome for the goal of net zero emissions.
- Most CO_2 capture technologies can be applied to several if not all EIIs. However, all capture technologies are capital intensive and energy demanding. However, waste heat from EIIs could be monetizable for CO_2 capture processes.

Mr. Copin then described the organization of the task force's final report. In addition to the usual background and recommendations sections, the report will contain specific information about various EII sectors (such as steel production). These include:

- Each sector's contribution to today's economies and to their growth.
- A geographical analysis of its production.
- The trends in emissions.
- The main CO_2 emissions patterns for typical facilities of the sector.
- Other ways than CCUS to decrease CO_2 emissions.
- How CCUS is needed to achieve net zero emissions.
- The development status of CCUS in the sector.
- The main challenges to CCUS development.

Mr. Copin ended his presentation by stating that the task force was unfortunately not able to have the report completed in time for the current meeting, but will have it finalized and launched in time for the next meeting.

14. Final Report from the Improved Pore Space Utilisation Task Force

Task Force Co-Chair Max Watson gave a brief summary on the task force, which had been established at the November 2015 meeting in Riyadh. Task force members include

Australia and the United Kingdom (as co-chairs), France, Japan, Norway, the United Arab Emirates, and the IEAGHG. The objective of the task force had been to investigate the current status of techniques that have the potential to improve how well the capacity of reservoirs for CO_2 storage are utilised. The task force has completed its final report (which is downloadable from the CSLF website) and has disbanded. Dr. Watson stated that his presentation was to summarise some of the outcomes of the task force's activities and to present any recommendations from the final report.

Dr. Watson provided a brief description of the contents of the final report, which contains sections on non-technical issues related to improved pore space utilisation, improved sweep efficiency from the oil and gas sector, technologies for improved pore space utilisation, and ranked technique effectiveness and technique status. Cost benefits include reduced cost of monitoring as well as reduced costs (due to improved economies of scale) for exploration/appraisal of storage sites, transport of CO_2, and storage site operation. There would also be increased storage security from implementation of improved pore space utilisation. Dr. Watson then went on to briefly describe some of the improved pore space utilisation techniques that are detailed in the final report. These include improved sweep efficiency techniques, pressure management, microbubble CO_2 injection, CO_2 saturated water injection and geothermal energy, and compositional, temperature and pressure swing injection.

Dr. Watson concluded the presentation by stating that while the task force focused on leveraging the pore space to maximise development investment and minimise area for monitoring, it did not include any investigation into reservoir management from a risk basis. A recommendation from the task force is for a future new task force to investigate CO_2 storage reservoir management, incorporating the task force's learnings as well as existing and emerging reservoir management practices and well engineering practices, particularly from CSLF-recognized commercial CO_2 storage projects.

15. Report from the Non-Enhanced Hydrocarbon Recovery (EHR) Utilization Options Task Force

Task Force Chair Mark Ackiewicz gave a brief update on the task force, which had been established at the April 2018 meeting in Venice. A previous task force related to this topic (which had then included EHR such as enhanced oil recovery [CO_2-EOR] and enhanced gas recovery [CO_2-EGR]) had existed between 2011 and 2013 and had issued two reports before disbanding. Key messages from these two reports were that:

- There are many CO_2 utilization options.
- CO_2-EOR is the most near-term utilization option.
- Non-EOR CO_2 utilization options are at varying degrees of commercial readiness and technical maturity.
- Early R&D or pilot-scale activities should focus on addressing techno-economic challenges, verifying performance, and supporting smaller-scale tests of first generation technologies and designs.
- More detailed technical, economic, and environmental analyses should be conducted.

Mr. Ackiewicz reported that following the disbanding of that task force there have been many other kinds of activities on this topic, including incentives and policy changes of various kinds (including the United States '45Q' tax credit which now includes other utilization options such as conversion of CO_2 into fuels, chemicals, and other useful

products). Mr. Ackiewicz also noted that there have been more recent reports by academia, government, and independent organizations such as the IEAGHG. There have also been, and continue to be, conferences entirely focused on CO_2 utilization or having that topic for one or more sessions. And, to date, there has been one CSLF-recognized project on CO_2 utilization: the Carbon Capture and Utilization / CO_2 Network Project located in Jubail, Saudi Arabia and sponsored by SABIC, where up to 1,500 tonnes per day of CO_2 is being captured and transported via pipeline to industrial sites where it is used as feedstock for production of methanol, urea, oxy-alcohols, and polycarbonates. Mr. Ackiewicz stated that the main goal of the task force is to add value and not re-invent: the task force is checking on the status of non-EHR CO_2 utilization by reviewing the reports, projects, conferences, activities, and projects of various kinds, and government initiatives that have occurred since the closure of the previous task force. The task force is developing a summary report and recommended next steps of the task force which will be presented at the next Technical Group meeting.

16. Report from the CO_2 Hubs and Infrastructure Task Force

Task Force Chair Lars Ingolf Eide gave a presentation which provided a summary of the task force's preliminary "Phase 0" activities. This task force was formed at the Melbourne meeting in October 2018 with the short-term mandate of reviewing what has previously been done (e.g., reports and conference presentations) on the topic. Task force members for the preliminary phase are Norway (lead), Australia, Brazil, Canada, and the United Kingdom. Mr. Eide began his presentation by providing some definitions of concepts, as it pertains to CCS:

- A 'cluster' is a geographic concentration of interconnected industries and/or other entities which generate, store, or utilize CO_2.
- A 'hub' is a central collection or distribution point for CO_2. One hub would service the collection of CO_2 from a capture cluster or distribution of CO_2 to a storage cluster.
- A 'network' includes CO_2 hubs and clusters and brings together many elements of the CCS value chain (including CO_2 source, capture, transport, injection, and storage).
- 'Infrastructure' is the physical parts of a CO_2 network, including single or shared CO_2 capture facilities, temporary storage facilities, injection facilities, pipelines, and ships.

Mr. Eide stated that this task force had been formed in order to follow up on one of the priority recommendations from the 2017 TRM, on facilitating CCS infrastructure development. The near-term goals, concerning that recommendation, is to design and initiate large-scale CO_2 hubs that integrate capture, transport and storage including matching of sources and sinks, and to develop commercial models for industrial and power CCS chains. There are few technology gaps for implementing CCS networks, and potential benefits are many. However, to date, there are only three operational CO_2 onshore networks (all in the United States), one operational offshore network (in Brazil), and one network under construction (in Canada). In contrast, there are many clusters that exist in various parts of the world that do not yet have infrastructure available to transport and store the CO_2.

Mr. Eide stated that the task force, as part of its "Phase 0" activities, had reviewed several new documents pertaining to hubs, clusters and infrastructure that had not been cited by the 2017 TRM, including an IEAGHG report on "Enabling the Deployment of Industrial

CCS Clusters" and a United States Department of Energy report on "Siting and Regulating Carbon Capture, Utilization and Storage Infrastructure". The major conclusion from "Phase 0" is that progress on infrastructure development is lagging behind what is necessary to reach the storage targets described in the 2017 TRM and that strong action is therefore required. Mr. Eide closed his presentation by listing four of the task force's recommendations:

- The task force should continue to monitor the development of networks for CCUS, including clusters, hubs and infrastructure.
- The task force should present updates on an annual basis, without the need for extensive task force reports.
- The CSLF should consider organizing workshops on this topic in cooperation with GCCSI, IEAGHG, the International CCS Knowledge Centre, CO_2GeoNet, and Mission Innovation.
- The CEM Ministers and decision makers from industry should facilitate (e.g., through co-funding) cross-industry projects to ensure the lowest total cost for the combined capture, transportation, utilization, and/or storage infrastructure and networks.

There was consensus that the task force should continue indefinitely and provide annual presentations on this topic.

17. Update on the Technical Group Task Force Action Plan

Technical Group Chair Åse Slagtern made a short presentation that summarized existing Technical Group activities and possible new ones. There have been five active task forces (or equivalent) besides the PIRT: Improved Pore Space Utilization (co-chaired by Australia and the United Kingdom, formed in 2015), CCS for Energy Intensive Industries (chaired by France, formed in 2016), Non-EHR Utilization Options (chaired by the United States, formed in 2018), the CO_2 Hubs and Infrastructure Task Force (chaired by Norway, formed in 2018), and the Ad Hoc Committee (chaired by the United States, formed in 2018). However, the Improved Pore Space Utilization Task Force has recently completed its activities and the CCS for Energy Intensive Industries will soon be completing its activities. Ms. Slagtern stated that there are many other potential topics of interest that the Technical Group could undertake with new task forces, including a continuation of the Pore Space Utilisation Task Force, a Business Models task force, and a task force for engagement of the academic community.

Ms. Slagtern noted that the next agenda item was to explore possible engagement of the academic community and any Technical Group actions would be decided after that. As for a possible follow-on to the Pore Space Utilisation Task Force, Max Watson stated that he would be willing to engage project partners of his organization (CO2CRC) to see if they would be willing to provide field-based information about CO_2 reservoir management. If so, there could be an opportunity to form a new task force to review and summarize publicly-available information on that topic. Dr. Watson agreed to report back at the next Technical Group meeting on the feasibility of a Reservoir Management future activity. Concerning a possible new activity on Business Models, Mark Ackiewicz stated that the Policy Group should be queried as to what, if anything, it is doing on this topic, and that a possible way to proceed would be with a joint Technical Group / Policy Group Task Force, if that was desirable. Sallie Greenberg mentioned that a scoping workshop on this topic could also be a good joint activity with the Policy Group. There was agreement to inquire to the Policy Group to see if mutual interest exists.

18. Engagement of Academic Community

Technical Group Chair Åse Slagtern gave a short presentation which summarized the CSLF's previous activities toward engagement of the academic community. This activity has existed since 2009, though it was mostly dormant during the years 2010-2014. At the 2015 Mid-Year Meeting in Regina, the Policy Group re-activated this initiative, with the United States and Mexico as co-leads. A half-day workshop was held at the CSLF's 2016 Mid-Year Meeting in London, which resulted in several recommendations for future Policy Group actions in areas such as international networks, research exchanges, and summer schools. Specific recommendations were to utilize existing resources and linkages to leverage existing connections and foster new connections while avoiding duplication of effort, focus on best practices and showcase talent and technologies. Priority areas were identified as training and academic resources, communications, and capacity building. However, subsequent to the 2016 Workshop, activity in this area has faded and there are no current Policy Group actions.

Ms. Slagtern stated that during the roll-up to the Champaign meeting it was determined that sufficient interest existed within the Technical Group to re-establish an Academic Task Force, and the presence at the meeting of many attendees from the academic community appeared to provide sufficient verification. However, a way forward was needed, and to initiate discussion Ms. Slagtern provided the following list of questions:

- What kinds of outcomes would be desirable, given that the CSLF is not a funding organization?
- What kinds of activities are actually do-able, given the constraints of available time and resources?
- What can be accomplished prior to the next Technical Group meeting?
- What kind of ongoing interaction would the academic community like to have with the Technical Group?
- Are there activities that could feed into measuring progress of the TRM?
- Who would take the lead?

Ensuing discussion explored some of these points. Ceri Vincent inquired if the CSLF could endorse academic programs such as the CO_2GeoNet's Masters program. Sallie Greenberg responded that another ad hoc committee, perhaps similar to the PIRT, might be needed to review and recommend such programs. Katherine Romanak suggested that CSLF capacity building funds could be used, as they were for an Offshore CO_2 Storage workshop in 2017, to support activities such as a proposed three-way capacity building collaboration between the University of Texas at Austin, the University of the West Indies, and the University of Trinidad and Tobago. Ms. Slagtern responded that such funds were under the control of the Policy Group and that she could therefore not comment on that proposal. Concerning the kinds of activities that are do-able, Max Watson cautioned that the Technical Group should take care not to duplicate any activities that other organizations such as the IEAGHG are already engaged in with the academic community, and also inquired if re-establishment of an Academic Task Force would be intended to support students or for supporting connections between R&D academics, and this would respond to what industry needs. Xian Zhang noted that since the CSLF is not a funding organization, there needs to be clarification on exactly what it can offer to the academic community.

In the end, there was consensus to form a new task force to explore engagement with the academic community. Australia (Max Watson) and the United Kingdom (Brian Allison)

volunteered to be the co-leads, with Canada (Eddy Chui) also participating. They will gather information (as well as consult with the Policy Group) and report back at the next Technical Group meeting with recommendations on what should happen next in this area.

19. Adjourn for the Evening

Technical Group Chair Åse Slagtern thanked Keri Canaday and Dan Byers of the Illinois State Geological Survey for their assistance concerning meeting organization and logistics, thanked Lars Ingolf Eide for facilitating the telephone link-up during the CCS for Energy Intensive Industries Task Force agenda item, and adjourned the meeting for the evening.

Friday Session

20. Welcome Back

Technical Group Chair Åse Slagtern, welcomed attendees to the second day of the Technical Group meeting and called the meeting to order.

21. Status of CCUS in the United States

Mark Ackiewicz, Director of the Department of Energy's Division of CCUS R&D, gave an overview presentation on the status of CCUS in the United States. Mr. Ackiewicz began by showing a domestic energy consumption graph which projected that fossil fuels would be a major part of the United States energy mix for decades to come. Fossil energy is critical in all U.S. domestic sectors, with the price of natural gas a key factor in projecting the future U.S. energy mix. Petroleum currently accounts for approximately 37% of the total U.S. energy supply and because of this there is a strong continuing interest in CO_2-EOR, with 136 active EOR projects (as of 2014) which have increased petroleum production by approximately 300,000 barrels per day. Most of these projects are located in west Texas, where an extensive CO_2 pipeline infrastructure exists. Other CO_2 pipeline complexes are located along the Gulf Coast and in the upper Midwest.

Mr. Ackiewicz provided a short summary of the three major CCUS demonstration projects in the United States. The Air Products facility in Port Arthur, Texas, began operation in 2013 and captures CO_2 from two large steam methane reformers. More than five million metric tons of CO_2 have been captured and transported via pipeline for CO_2-EOR since the project began. The Petra Nova CCS Project, in Thompsons, Texas, began operation in 2017 and captures CO_2 from coal-fueled power plant flue gas. Approximately 2.5 million metric tons of CO_2 have been captured and transported via pipeline for CO_2-EOR since the project began. The Illinois Industrial CCS Project, located in Decatur, Illinois, also began operation in 2017 and captures CO_2 produced during ethanol biofuel production. Approximately one million metric tons of CO_2 has been captured and 0.8 million metric tons stored in a deep saline geologic formation since the project began.

Mr. Ackiewicz stated that funding for the Department of Energy's CCUS R&D Program has averaged approximately US$200 million per year for the past four years, with carbon capture technology R&D receiving about half of that amount and carbon storage slightly less than half. Carbon utilization has averaged approximately US$11 million per year during that time period. High-level program goals and challenges include reducing the cost of CO_2 capture by 50% (with a goal of US$30 per metric ton by the year 2030), developing viable CO_2 utilization alternatives, and reducing the risk of CO_2 geologic

storage by improving monitoring and simulation. Concerning CO_2 capture, there have been more than 200 R&D projects funded over the past 20 years including the National Carbon Capture Center, which since its founding in 2008 has amassed more than 100,000 test hours for technologies from the United States and six other countries. Future CO_2 capture activities are expected to include R&D on transformational carbon capture technologies for both pre- and post-combustion CO_2 capture, process development / design (from R&D and with the Carbon Capture Simulation Initiative for Industry), technology validation (via the National Carbon Capture Center and other test centers), engineering studies for commercial carbon capture plants, and R&D on direct air capture of CO_2. Concerning CO_2 utilization, there are approximately 20 active projects across the areas of biological capture / conversion, fuels and chemicals, and mineralization and cements. In the area of CO_2 storage, there are several ongoing initiatives including the Carbon Storage Assurance Facility Enterprise (CarbonSAFE) whose goal is to identify and certify geologic storage sites for commercial volumes of CO_2. Also, the Regional Carbon Sequestration Partnerships, which include more than 400 different organizations across 43 U.S. states and four Canadian provinces, have been working since 2003 at developing the infrastructure for wide scale deployment of CCUS, and have been engaging regional governments, determining regional carbon sequestration benefits, establishing monitoring and verification protocols, and validating sequestration technology and infrastructure.

Mr. Ackiewicz went on to briefly describe the major policy incentive for CCUS in the United States – the '45Q' tax credit which is available for qualified facilities where the original planning and design includes CO_2 capture equipment and whose construction starts by the beginning of 2024. Tax credits of US$50 per ton are available for dedicated storage (e.g., in deep saline formations) and US$35 per ton for CO_2-EOR. These credits are available for power plants where at least 500,000 tons of CO_2 per year are removed, industrial facilities where at least 100,000 tons of CO_2 per year are removed, and direct air capture facilities where at least 100,000 tons of CO_2 per year are removed. These credits can be claimed by the owner of the CO_2 capture equipment or transferred to the disposal / utilization entity.

Mr. Ackiewicz closed his presentation by providing the United States role in multilateral CCUS partnerships. Besides the CSLF, these include the International Energy Agency (IEA) where the U.S. is currently Chair of the Working Party on Fossil Fuels and Executive Committee member of other IEA committees (such as the IEAGHG), the Clean Energy Ministerial where the United States is CCUS Initiative Lead, the Mission Innovation CCUS Initiative, the ACT initiative, and the GCCSI. In all, the United States has been a global leader on CCUS research, development, and deployment.

22. Update on CSLF-recognized Project: NET Power Demonstration Project

Adam Goff, representing project sponsor 8 Rivers, gave a detailed overview presentation about the NET Power Demonstration Project, a 50-megawatt (thermal) natural gas-fueled pilot project, located near Houston, Texas, USA, which had become a CSLF-recognized project at the 2016 CSLF Annual Meeting in Tokyo. The overall objective is to demonstrate the performance of the Allam Cycle, a next-generation oxyfuel gas turbine-derived power cycle to produce power at low cost and with no atmospheric emissions. The project includes construction and operation of a 50 megawatts-thermal (MW_{th}) natural gas-fueled pilot plant and also design of a much larger proposed commercial-scale project. The anticipated outcome of the project is verification of the performance of the Allam Cycle, its control system and components, and purity of the produced CO_2 with

learnings being used in the design of a future commercial-scale project using this technology. Concerning Allam Cycle technology, Mr. Goff stated that instead of steam, supercritical CO_2 is used to drive the turbine and is then captured into a pipeline at no additional cost. CO_2 capture is inherent to the system, and selling CO_2 is a key source of revenue. Mr. Goff stated by using supercritical CO_2 as a working fluid, the Allam Cycle can reach the approximately the same efficiency as a conventional natural gas power plant while achieving over 97% carbon capture with zero air pollutants.

Mr. Goff stated that the NET Power team consists of 8 Rivers as inventor and designer, Toshiba as turbine designer and supplier, Exelon for engineering and construction and also sales expertise, McDermott for operations expertise, and Oxy Low Carbon Ventures for CO_2 and project commissioning expertise. Exelon, McDermott, and Oxy are also investors in the project. The overall cost, including design, construction and the testing program, is budgeted at more than US$160 million. Construction began in 2016 and was completed at the end of 2017. Commissioning and combustor tests were completed in 2018 with full cycle testing now in progress, and the project will be supplying power to the grid this year. Mr. Goff stated that early results indicate that Allam Cycle performance has matched computer models.

Mr. Goff stated that a commercial project would be approximately 300 megawatts, and NET Power has several such potential projects under consideration. Ideally, these would be located in places where CO_2 has value, in order to enhance the economics, and there is some urgency to do some of these projects prior to the '45Q' January 2024 project construction deadline for tax credit eligibility. Mr. Goff closed his presentation by stating that an Allam Cycle project can be used for energy storage, as generated electricity can be used in off-peak hours to separate oxygen for future power cycle use. NET Power is also working to adapt the Allam Cycle for use with syngas from coal gasification and may eventually be interested in smaller combined heat and power (CHP) applications that are fueled by natural gas.

23. Update from CSLF-recognized Project: Michigan Basin Development Phase Project

Neeraj Gupta, representing project lead Battelle and the Midwest Regional Carbon Sequestration Partnership (MRCSP), gave a technically detailed presentation about the Michigan Basin Development Phase Project, located at several sites in Michigan and nearby states in the USA, which had become a CSLF-recognized project at the 5th CSLF Ministerial Meeting in Washington in 2013. Over its duration this project will inject and monitor a total of one million tonnes of CO_2 (obtained from natural gas processing) in collaboration with CO_2-EOR operations. Project objectives are to evaluate CO_2 injectivity, migration and containment. Project components include seismic analysis to reduce uncertainties in storage reservoir characterization, core analyses to quantify reservoir properties, and evaluation of alternatives for improving CO_2 injectivity. One of the results from the project has been development of an atlas of the storage site geology where CO_2 injection is occurring or is possible. This has revealed that there is significant regional potential for both CO_2 geologic storage and CO_2-EOR, with more than 250 million metric tons of CO_2 storage possible and more than 100 million barrels of oil recoverable.

Dr. Gupta stated in addition to the technical results obtained, the project, via the MRCSP, has done a considerable amount of outreach in sharing lessons learned in order to foster CCUS development. This has included stakeholder meetings, giving presentations and writing papers for conferences, producing factsheets, and developing a comprehensive

website. Dr. Gupta closed his presentation by stating that all critical milestones and objectives are on track, though significant work remains to advance CCUS and share knowledge from MRCSP activities. The Michigan Basin Project is expected to conclude in 2020, and the MRCSP will merge with the neighboring Midwest Geological Sequestration Consortium.

24. Update from CSLF-recognized Project: SECARB Early Test at Cranfield Project

Susan Hovorka, representing project lead University of Texas's Bureau of Economic Geology, gave a technically detailed presentation about the SECARB Project, located near Cranfield, Mississippi, USA, which had become a CSLF-recognized project at the 2010 CSLF Annual Meeting in Warsaw. This large-scale project, now concluded, involved injection and monitoring of approximately one million metric tons of CO_2 per year, for more than a year-and-a-half, into a deep saline reservoir associated with a commercial enhanced oil recovery operation, with the focus of this project on the CO_2 storage and monitoring aspects. The project promoted the building of experience necessary for the validation and deployment of carbon sequestration technologies in the United States, and increased technical competence and public confidence that large volumes of CO_2 can be safely injected and stored. Components of the project also included public outreach and education, site permitting, and implementation of an extensive data collection, modeling, and monitoring plan. This project sets the stage for subsequent large-scale integrated projects involving post-combustion CO_2 capture, transportation via pipeline, and injection into deep saline formations.

Dr. Hovorka stated that the project had begun back in 2006 with site identification, with reservoir characterization and development of the monitoring plan commencing at the beginning of 2007. Injection and monitoring activities began in 2008 and although commercial injection is continuing at the site, project monitoring activities ended midway through 2015. Data assessment and technology transfer activities are continuing. Dr. Hovorka stated that there have been very many publications and presentations derived from the project, and a major accomplishment has been technology transfer of monitoring technologies to other projects such as the Petra Nova Project and the Air Products-Hastings Commercial EOR Project. Dr. Hovorka concluded her presentation by listing several possible next steps, one of which being education about CCUS to stakeholders, policy makers for business and financial organizations, students, and the general public.

Following the conclusion of Dr. Hovorka's presentation, the SECARB Early Test at Cranfield Project was presented a CSLF Global Achievement Award in recognition of its advancement of CCS technologies. *(Note: CSLF Global Achievement Awards are presented to CSLF-recognized projects which have successfully concluded, or have achieved major milestones in terms of cumulative amount of CO_2 captured and/or stored.)*

25. Update from CSLF-recognized Projects: CCSI^2 and NRAP Initiatives

Grant Bromhal, representing the United States National Energy Technology Laboratory (NETL), gave a technically detailed presentation about two ongoing NETL initiatives: the Carbon Capture Simulation for Industry Impact (CCSI^2) and the National Risk Assessment Partnership (NRAP). Both of these had become CSLF-recognized projects at the 2017 CSLF Mid-Year Meeting in Abu Dhabi.

Concerning CCSI^2, Dr. Bromhal stated that this is a computational research initiative, with activities ongoing at NETL, four other National Laboratories, and five universities

across the United States. There is also collaboration from other organizations outside the United States including industry partners. The overall objective is to develop and utilize an integrated suite of computational tools (the CCSI Toolset) in order to support and accelerate the development, scale-up and commercialization of CO_2 capture technologies. The anticipated outcome is a significant reduction in the time that it takes to develop and scale-up new technologies in the energy sector. $CCSI^2$ will apply the CCSI Toolset, in partnership with industry, in the scale-up of new and innovative CO_2 capture technologies. A major focus of $CCSI^2$ is on model validation using the large-scale pilot test information from projects around the world to help predict design and operational performance at all scales including commercial demonstrations. These activities will help maximize the learning that occurs at each scale during technology development: early stage R&D, pilot scale, and demonstration scale.

Concerning NRAP, Dr. Bromhal stated that this is a risk assessment initiative, with activities ongoing at NETL and four other National Laboratories across the United States, including collaboration with industry, regulatory organizations, and other types of stakeholders. The overall objective is development of defensible, science-based methodologies and tools for quantifying leakage and seismic risks for long-term CO_2 geologic storage. Specifically, NRAP will improve the science base to address key questions related to environmental impacts from potential release of CO_2 or brine from storage reservoirs, and potential ground-motion impacts due to injection of CO_2. The anticipated outcome is removal of key barriers to the business case for CO_2 storage by providing the technical basis for quantifying long-term liability. To that end, NRAP has developed and released a series of computational tools (the NRAP Toolset) that are being used by a diverse set of stakeholders around the world. The toolset is expected to help storage site operators design and apply monitoring and mitigation strategies, help regulators and their agents quantify risks and perform cost-benefit analyses for specific CCS projects, and provide a basis for financiers and regulators to invest in and approve CCS projects with greater confidence because costs long-term liability can be estimated more easily and with greater certainty.

26. Update from the Petra Nova Project

Greg Kennedy, representing project sponsor NRG Energy, gave a detailed overview presentation about the Petra Nova Project, located near Houston, Texas, USA. In addition to NRG Energy, project partners are JXTG Holdings, Hilcorp Energy, JBIC, and NEXI, and the project received a US$190 million grant from the United States Department of Energy as part of its Clean Coal Power Initiative. Petra Nova is currently the world's largest power plant-based CCUS project, with more than 2.8 million tons of CO_2 captured since project start-up in 2017. The project uses a 240-megawatt equivalent slipstream of flue gas from NRG's 640-megawatt W.A. Parish coal-fueled power plant. CO_2 accounts for about 13% of the flue gas and the project captures more than 90% of the CO_2 from the slipstream. When operating at 100%, the project captures approximately 5,200 tons of CO_2 per day. A dedicated natural gas-fueled CHP facility, at the power plant site, provides electrical power and steam for use by the carbon capture unit, with any surplus power sold to the grid. Mr. Kennedy stated that the captured CO_2 is utilized for CO_2-EOR after being transported by an 81-mile (130-kilometer) pipeline to the West Ranch Oil Field southwest of Houston. This has resulted in boosting production of oil in the West Ranch field, which is partly owned by the Petra Nova Project, from about 300 barrels per day to more than 4,000 barrels per day.

Mr. Kennedy stated that the CO_2-EOR part of the project includes a comprehensive monitoring, verification and accounting (MVA) plan that was developed and is being managed by the University of Texas's Bureau of Economic Geology during the Department of Energy's three-year demonstration period. Key components include development of a fluid flow simulation model using actual production data, mass balance accounting for injected CO_2, pressure monitoring, pre-injection fluid sampling, groundwater monitoring, and soil gas monitoring.

Mr. Kennedy closed his presentation by mentioning the areas of current focus for NRG concerning the project. These include optimization of the technology being used for the project, optimization of project economics, continuing to develop operational expertise, and evaluating / optimizing tax incentives for the project. Mr. Kennedy stated that interest in the Petra Nova Project remains high, from the large number of international, domestic and government tours the facility has welcomed, as well as the numerous speaking engagement requests and references about the project in various technical and media publications. Mr. Kennedy indicated that the project would continue to be receptive to these requests even after the three-year demonstration period has concluded.

27. New Materials Discovery in Carbon Capture Solvents and Membranes

Jan Steckel, representing NETL's Computational Materials Engineering Team, gave a technically detailed presentation about NETL's activities toward developing advanced CO_2 separation technologies with the assist of computational methods. NETL has an active in-house research program focused on advanced CO_2 capture technologies which have been greatly aided by process simulation and modeling activities. Dr. Steckel stated that in the area of advanced solvents, a computational study is being undertaken to screen for novel pre-combustion capture solvents which are hydrophobic, which have large CO_2 solubility and a large CO_2/H_2 solubility selectivity, low viscosity, a low vapor pressure, and low foaming tendency. The overall computational strategy utilizes a comprehensive National Institute of Standards and Technology (NIST) database of pure compounds to obtain physical properties of candidate solvent components, an in-house computational database that covers quantum mechanics for gas-chemical function group interactions, and in-house simulations that are run using a supercomputer. Promising solvent formulations are then constituted and tested at the University of North Dakota's Energy and Environmental Research Center.

Dr. Steckel stated that in the area of advanced gas separation membranes, computational methods are being used to identify polymer membrane compositions which exhibit good mechanical properties, are of relatively low cost, and have high selectivity. Specifically, the emphasis is on mixed matrix membranes (MMMs) which combine polymer and metal organic framework (MOF) into a composite material. One challenge for making MMMs is that pairing the 'best' polymer and the 'best' MOF does not necessarily result in the 'best' MMM. A study goal is therefore to perform comprehensive computational screenings to determine which MOF to pair with which polymer and to provide insight into the relationship between MOF and MMM properties. This can all be done with process simulations.

Dr. Steckel closed her presentation by presenting some of the results obtained in these two computational research areas, and by acknowledging the project managers who are overseeing these activities.

28. Preview of Project Tundra

Neil Wildgust of the University of North Dakota's Energy & Environmental Research Center gave an overview presentation about Minnkota Power Cooperative's proposed Project Tundra, which would be the world's largest integrated post-combustion CO_2 capture project. The project would retrofit Unit 2 of the Milton R. Young Power Plant, in central North Dakota, with amine-based CO_2 capture technology which would remove up to 95% of the unit's CO_2 emissions. This CO_2 could then be transported via a proposed 100-mile (160-kilometer) pipeline to an oil field for CO_2-EOR or, alternatively, stored in a deep saline formation near the power plant site. Mr. Wildgust stated that the project was modeled after the Petra Nova Project in terms of technology used and would have the potential of removing from 2.3 million to as much as 3.6 million tons of CO_2 per year.

Mr. Wildgust closed the presentation by stating that Minnkota is very interested in this proposed project, as the new '45Q' tax credits have changed everything in terms of making projects like this economically attractive. For the proposed Project Tundra, these tax credits would amount to approximately US$1 billion. However, Minnkota has stated that it cannot monetize these tax credits, which means it will need a partner for the project.

29. Update from the International Test Center Network (ITCN)

Frank Morton, representing the National Carbon Capture Center in the United States, and Jon Gibbins, representing the United Kingdom CCS Research Centre, gave a short presentation about the ITCN and its collaborative activities. Mr. Morton stated that the ITCN was launched in 2013 to accelerate CCS technology development, and currently has member organizations in Australia, Canada, China, Germany, Japan, Korea, Norway, the United Kingdom, and the United States. The ITCN's main function is to facilitate knowledge sharing of operational experience and non-confidential information for CO_2 capture technologies, in terms of facility operations, facility funding, safety, and analytical techniques. Among the objectives of the ITCN are increasing insight and awareness of different technologies that may reduce risks and increase investments in CO_2 capture technologies and enhancing public awareness and acceptance of the technologies involved. There are several specific goals:

- Increase the value of public and private CCS research and technology investments through increased sharing of lessons learned and results from parallel activities.
- Identify one technical focus area per year and publish a summary report.
- Continue emphasis on technical and non-technical collaboration, including determining new areas for such collaborations.
- Collaborate on partnerships for scale-up of technology and responses to funding opportunities.

Mr. Morton and Prof. Gibbins then provided a response to an action item from the October 2018 Technical Group meeting in Melbourne: *"The International Test Center Network will provide the Technical Group a list of specific recurring challenges that need to be addressed for specific CO_2 capture technologies.*" Current technology challenges are as follows:

- Solvent-based Capture Technology
  - Solvent post-combustion capture is the only technology that is past Technology Readiness Level 9 (TRL-9). Challenge is raising the Commercial Readiness Index (CRI).

- Oxy-fuel
  - Atmospheric pressure technically feasible but appears to be awaiting a commercial driver.
- Membranes
  - Proprietary developments are progressing.
- Solids
  - Proprietary developments are progressing.

Challenges for next generation technologies are as follows:

- Supercritical CO_2 Power Cycle
  - Heat exchanger durability (advanced materials and high temperature metal alloys) and thermal management.
  - Fundamental knowledge gap on combustion (e.g., chemical kinetics for combustor development, emission prediction, and impact of impurities).
- Combustion Alternatives (i.e., advanced fuel cells with CCUS)
  - Increasing the CO_2 capture rate per module.

Prof. Gibbins stated that the CRI for post-combustion CO_2 capture needs to be increased by driving sub-systems up through technology readiness levels. This can be done based on learning by doing. In particular, government-funded R&D and innovation can help to evolve the CRI on post-combustion capture technologies. However, this requires a good knowledge transfer between large-scale facilities and the research, development, and investment communities. Also, open-technology / open-access post-combustion capture is a key enabler for international partnerships.

Prof. Gibbins closed the presentation by mentioning previous ITCN events, including a workshop on second generation open access solvents that was held in Hong Kong in June 2018 and a workshop on practical aspects of post-combustion capture retrofits based on open access information that was held in Sheffield, U.K. earlier in April. The ITCN is also collaborating with the Guangdong CCUS Centre in China on a 50 metric ton-per-day pilot test facility and the Guangdong Centre's open technology deployment plans. Additional information is available at the ITCN's website.

30. Report from the Ad Hoc Committee

Ad Hoc Committee Chair Sallie Greenberg began a presentation which summarized the committee's activities. This group was created at the April 2018 Technical Group meeting in Venice with a mandate to monitor progress on the overall goals from the 2017 TRM:

- Long-term isolation from the atmosphere of at least 400 megatonnes (Mt) of CO_2 per year by 2025 (or have permanently captured and stored 1,800 Mt CO_2);
- Long-term isolation from the atmosphere of at least 2,400 Mt of CO_2 per year by 2035 (or have permanently captured and stored 16,000 Mt CO_2);

and also to monitor progress on four recommended priority actions as identified by the TRM:

- Facilitate CCS infrastructure development;
- Leverage existing large-scale projects to promote knowledge-exchange opportunities;
- Drive down costs along the entire CCS chain through RD&D; and
- Facilitate innovative business models for CCS projects.

The overall objective is to identify and recommend corrective actions in areas where progress is slow and to report findings to CSLF Ministers. To that end, the Committee developed a questionnaire for CSLF delegates to provide their input on whether or not there had been any progress on globally addressing the TRM's recommended priority actions and achieving the 2025 goal. A 'stoplight' rating system was devised where 'Green' indicates that there has been good progress toward reaching the target; 'Yellow' indicates that there is room for improvement and that progress is insufficient to reach the target unless new actions are initiated; and 'Red' indicates that strong actions are required as there has been poor progress and the target will not be reached. Dr. Greenberg stated that only a limited amount of time had been available prior to the current meeting to develop the questionnaire and gather information, and for that reason it was mostly the members of the Ad Hoc Committee (representing a broad and expert cross-section of the CCUS community) who provided input which was then condensed into an overall status for the target and the four priority actions.

Lars Ingolf Eide described results from the Ad Hoc Committee's deliberation. The overall 2025 target for CO_2 storage received a 'Red' rating, as there needs to be a ten-fold increase in annual storage capacity in the next six years. Projects in advanced or early development will not add sufficient capacity by 2025 where that target can be met. Mr. Eide then provided the following results concerning the four priority recommendations:

- "Facilitate CCS infrastructure development" received a 'Red' rating. There have been many good plans and studies, but no CO_2 infrastructure / network projects have come online in the past few years. Also, no infrastructure project passed the Final Investment Decision (FID) gate in 2018.
- "Leverage existing large-scale projects" received a 'Green' rating. There has been active leveraging through CSLF meetings, by the International CCS Knowledge Centre, and in various conferences and reports. However, it is not known which projects have used knowledge and experience from other projects.
- "Drive down costs along the entire CCS chain through RD&D" received a 'Yellow' rating. There is much good research going on that progresses CCUS technologies but no breakthrough technologies reported or identified at TRL-6 or higher have convincing evidence of significant cost reductions.
- "Facilitate innovative business models for CCS projects" received a 'Yellow' rating. There have been many good plans and studies, but progress on development of business models (except for those influenced by the '45Q' tax credits in the United States) has been lacking (perhaps due to absence of policy and regulatory environments).

Mr. Eide stated that a draft paper summarizing these results had been prepared for CSLF Policy Group consumption and also that a draft "Message from CSLF Technical Group to CEM and CSLF Ministers" paper had been prepared for the upcoming CEM meeting and includes the following four recommendations:

- **Foster a predictable business environment for development of large-scale CCUS projects**. This could include policy and financial incentives, a practical regulatory environment, cost or risk-sharing for early stage demonstration or commercial-scale projects, and stimulating cross-business and cross-border cooperation.
- **Facilitate (e.g., through co-funding) cross-industry projects** to ensure lowest total cost for the combined capture, transportation, utilization and/or storage infrastructure and networks.

- **Continue to promote RD&D investments in CCUS to drive down costs**:
  - Continue to fund early stage R&D and encourage transformative technologies as well as incremental advancement to progress technologies to the pilot-scale.
  - Support continued RD&D efforts that promote commercial deployment and business opportunities for more advanced carbon utilization, in particular for early-stage technologies. Lifecycle analyses should continue to ensure that technologies result in net greenhouse gas emissions reductions.
  - Continue to promote global RD&D collaboration that leverages knowledge, capabilities, facilities and funding that further drives down costs and increases the availability of CCUS as a greenhouse gas mitigation option around the world.
- **Continue to promote knowledge-sharing from large-scale projects**. This is important in framing continued RD&D and informing the development and refinement of business models for CCUS deployment.

Mr. Eide closed the presentation by stating that a possible forward work mode for the Ad Hoc Committee would build on the approach used by the Ad Hoc Committee, including results from the questionnaire, with four smaller working groups within the committee set up to follow up and report on progress toward the four priority recommendations. This approach should involve Technical Group cooperation with allied organizations (GCCSI, IEAGHG, and the CO_2GeoNet Association) as well as other parties with interests in CCUS (for example, the International CCS Knowledge Centre, the IEA, and sponsors of recognized CSLF projects). The Ad Hoc Committee would report annually with results distributed to CSLF delegates several weeks prior to each year's Technical Group Mid-Year Meeting so that delegates would have the opportunity to provide comments prior to or at the Mid-Year Meeting.

In the ensuing discussion, there was consensus that the Ad Hoc Committee will continue its activities for the foreseeable future and that progress toward CO_2 utilization will be a fifth area which the committee includes in its annual report. Mr. Eide's suggestion for the creation of Ad Hoc Committee working groups was accepted, with the following leads:

- CCS infrastructure development. (Norway, with Lars Ingolf Eide as lead. Brian Allison [United Kingdom], Eddy Chui [Canada], Harry Schreurs [Netherlands], and Max Watson [Australia] also volunteered to assist.)
- Leverage existing large-scale projects. (PIRT, with Martine Woolf as lead. Max Watson [Australia], Eddy Chui [Canada], and the IEAGHG also volunteered to assist.)
- RD&D to drive down costs along the entire CCS chain. (Canada, with Mike Monea as lead. Eddy Chui [Canada], Pieter Smeets [Saudi Arabia], Max Watson [Australia], the CO_2GeoNet Association, and the IEAGHG also volunteered to assist.)
- Innovative business models for CCS projects. (China, with Xian Zhang as lead. Mark Ackiewicz [United States], Eddy Chui [Canada], Lars Ingolf Eide [Norway], and Pieter Smeets [Saudi Arabia] also volunteered to assist.)
- Facilitate implementation of CO_2 utilization. (United States, with Mark Ackiewicz as lead. Eddy Chui [Canada] and Pieter Smeets [Saudi Arabia] also volunteered to assist.)

Dr. Greenberg recommended that to simplify the situation, the leads for the working groups should develop their own methodologies for gathering information and after doing so should decide the overall 'stoplight' ratings. There was consensus for this approach. There was also consensus that the Ad Hoc Committee should give a progress report of some kind at the next Technical Group meeting. Dr. Greenberg agreed, and stated that the committee would have its overall methodology in place following the next Technical Group meeting.

31. Update on Future CSLF Meetings

Richard Lynch reported that the next Technical Group meeting would be hosted by France's delegation during the first week of November, with a venue in the Paris suburbs. More details will be forthcoming soon.

32. Open Discussion and New Business

There was no new business and no other announcements.

33. Closing Remarks / Adjourn

Technical Group Chair Åse Slagtern thanked Sallie Greenberg as head of the Midwest Geological Sequestration Consortium for hosting the meeting and site visit to the two CSLF-recognized projects in Illinois. Ms. Slagtern thanked the Secretariat for its pre- and post-meeting support, and the delegates and invited speakers for their active participation. She then adjourned the meeting.

Summary of Meeting Outcomes and Actions

- The CSLF-recognized SECARB Early Test at Cranfield Project was presented a CSLF Global Achievement Award in recognition of its advancement of CCS technologies.
- The CSLF Secretariat will send out a reminder email to Technical Group delegates, requesting comments on the Project Engagement Survey Form.
- The PIRT Chair will develop a proposal on how the PIRT will function going forward.
- The Policy Group is requested to provide additional details on the status of the CSLF's stakeholder engagement initiative and how remaining capacity building funds can be utilized.
- The Improved Pore Space Utilisation Task Force has completed its activities, published its final report (now available at the CSLF website), and disbanded.
- The CCUS for Energy Intensive Industries Task Force will complete its final report in time for the next Technical Group meeting.
- The Non-EHR Utilization Options Task Force will present a summary report and recommended next steps of the task force at the next Technical Group meeting.
- The CO_2 Hubs and Infrastructure Task Force was has completed its preliminary "Phase 0" activities. The task force will continue indefinitely and present updates annually.
- Australia's delegation agreed to investigate the feasibility of a CO_2 Storage Reservoir Management future activity and will report back at the next Technical Group meeting.
- The Technical Group will inquire to the Policy Group to see if mutual interest exists for joint activities on the topic of Business Models.

- A task force was formed to explore engagement with the academic community. Australia (Max Watson) and the United Kingdom (Brian Allison) are the co-leads, and will gather information (as well as consult with the Policy Group) and report back at the next Technical Group meeting with recommendations on what should happen next in this area.
- The Ad Hoc Committee will continue its activities for the foreseeable future and make annual reports on progress on the four priority recommendation areas. Also, progress toward CO_2 utilization will be an additional area which the committee includes in its annual report.
- Five working groups, under the Ad Hoc Committee, have been created and will follow progress toward the four priority recommendations cited in the TRM as well as progress toward CO_2 utilization. The leads for the working groups will develop their own methodologies for gathering information and will decide the overall 'stoplight' ratings.
- The Ad Hoc Committee should give a progress report of some kind at the next Technical Group meeting.
- The next Technical Group meeting will be hosted by France's delegation during the first week of November, with a venue in the Paris suburbs.