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Minutes of the Technical Group Meeting
Venice, Italy
Monday, 23 April 2018

LIST OF ATTENDEES

Chair — Åse Slagtern (Norway)

Delegates

Australia:	Andrew Barrett (*Vice Chair*), Mark Watson
Canada:	Eddy Chui (*Vice Chair*), Mike Monea
France:	Didier Bonijoly, David Savary, Dominique Copin
Italy:	Paulo Deiana, Sergio Persoglia
Japan:	Ryozo Tanaka, Ito Tanaka
Korea:	JaeGoo Shim, YiKyun Kwon
Netherlands:	Paul Ramsak
Norway:	Lars Ingolf Eide, Espen Kjærgård
Poland:	Anna Madyniak
Romania:	Sorin Anghel
Saudi Arabia:	Hamoud AlOtaibi, Tidjani Niass
United Kingdom:	Brian Allison
United States:	Mark Ackiewicz, Sallie Greenberg

Representatives of Allied Organizations

CO_2GeoNet:	Isabelle Czernichowski-Lauriol, Rowena Stead, Ceri Vincent, Ton Wildenborg
Global CCS Institute:	John Scowcroft
IEAGHG:	James Craig

CSLF Secretariat — Richard Lynch

Invited Speakers

France:	Marie Gastine (*BRGM and CO_2GeoNet*)
Italy:	Marcello Capra (*Ministry of Economic Development*)
Japan:	Takashi Kamijo (*MHI Engineering*)
Norway:	Svend Tollak Munkejord (*SINTEF Energy Research*)
United Kingdom:	Mark Crombie (*BP*)
United States:	James Sorensen (*University of North Dakota Energy and Environmental Technology Center*)

Observers

Canada:	Simon O'Brien (*Shell*)
Japan:	Chibumi Kimura, Makoto Susaki, and Yasuhiro Tatsumi (*MHI Engineering*)
Saudi Arabia:	Pieter Smeets (*SABIC*)
United Kingdom:	M. Pourkashanian (*University of Sheffield*)

1. Chairman's Welcome and Opening Remarks

The Chair of the Technical Group, Åse Slagtern, called the meeting to order and welcomed the delegates and observers to Venice. Ms. Slagtern mentioned that this would be a busy meeting, with presentations on many topics of interest including results from four CSLF-recognized projects plus review of one new project which has been nominated for CSLF recognition. Additionally, there would be presentations about several technology areas related to carbon capture and storage (CCS) as well as updates from the Technical Group's three allied organizations: the CO2GeoNet 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

Marcello Capra, Senior Expert at Italy's Ministry of Economic Development, welcomed the meeting attendees to Venice. Mr. Capra stated that Italy last hosted a CSLF Technical Group meeting in 2013, in Rome, and that Italy had become a Charter Member of the CSLF at its very first meeting in 2003. The current situation in Italy is that the Italian Government has launched a new National Energy Strategy which is focused on achieving climate and energy goals in harmony with 2015 Paris Climate Conference (COP21) targets. This includes phasing out all coal-fueled power plants by the year 2025. Dr. Capra stated that in regards to CCS, Italy is a participant in several European projects including ENOS (see below), and that the feasibility of CCS for the industrial sector such as in cement production is being investigated. Dr. Capra also mentioned that the current Technical Group meeting reinforces the strategic role of international collaboration for development of new energy technologies which mutually address energy security and environmental concerns, and that the meeting presents a great opportunity for a fruitful exchange of knowledge among meeting attendees.

3. Introduction of Delegates

Technical Group delegates present for the meeting introduced themselves. Thirteen of the twenty-six CSLF Members were represented. Observers from four 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 December 2017 Meeting in Abu Dhabi

The Minutes from the December 2017 Technical Group Meeting in Abu Dhabi were approved with no changes.

6. Report from CSLF Secretariat

Richard Lynch provided a report from the CSLF Secretariat which reviewed highlights from the December 2017 CSLF Ministerial Meeting. This was a five-day event, including a Conference of CSLF Ministers and their delegates, and also a Ministers' site visit to the Al Reyadah Carbon Capture, Utilization and Storage (CCUS) Project. Presentations from all meetings are online at the CSLF website.

Concerning the CSLF Conference of Ministers, Mr. Lynch stated that there were many key actions identified that are needed to accelerate the acceptance and large-scale deployment of CCUS:

- Encouraging the development of regional strategies that strengthen the business case for CCUS and accelerate its deployment;
- Exploring new utilization concepts beyond CO_2 enhanced oil recovery (CO_2-EOR) that have the potential to add commercial value;
- Supporting collaborative R&D on innovative next generation CCUS technologies with broad application to both the power and industrial sectors;
- Expanding stakeholder engagement and strengthening links with other global clean energy efforts to increase public awareness of the role of CCUS;
- Increasing global shared learnings on CCUS by disseminating best practices and lessons learned from CCUS projects; and
- Continuing to engage the public on CCUS and looking for ways to communicate effectively.

Mr. Lynch reported that there were also several other notable highlights from the meeting:

- The 2017 CSLF Technology Roadmap (TRM) was launched;
- Results from regional stakeholder surveys were documented and summarized;
- Three completed projects received CSLF Global Achievement Awards: the CANMET Energy Oxyfuel Project, the Lacq Integrated CCS Project, and the Plant Barry Integrated CCS Project; and
- The CO2CRC Otway Project Stage 3 received CSLF recognition.

Mr. Lynch concluded his presentation by reporting that the Technical Group meeting had its own set of outcomes:

- The Offshore CO_2-EOR Task Force issued its final report and has completed its activities;
- The Bioenergy with CCS (BECCS) Task Force and Improved Pore Space Utilization Task Forces were on schedule to present their final reports at the next Technical Group meeting;
- The CCS for Energy Intensive Industries Task Force was on schedule to present a draft report at the next Technical Group meeting;
- A new Task Force on Hydrogen Production and CCS was formed (but only for preliminary "Phase 0" activities);
- A detailed proposal for a new task force on CO_2 Capture by Mineralization would be presented at the next Technical Group meeting; and
- United States delegate Sallie Greenberg was designated as the Technical Group's liaison to the ISO TC265 technical committee on CO_2 capture, transport and geologic storage.

There was ensuing discussion concerning the CSLF Global Achievement Awards. Ryozo Tanaka inquired as to the criteria for eligibility. Mr. Lynch responded that any CSLF-recognized project which has been successfully concluded is eligible for an award. Also, large-scale projects which do not have an end date are eligible for an award when they achieve a major milestone, such as in the amount of CO_2 stored.

7. Update from the CO_2GeoNet Association

Ton Wildenborg, the 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. Dr. Wildenborg 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 29 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 information / communication.

Dr. Wildenborg then provided an update on recent activities of the organization. Since the December 2017 CSLF Ministerial meeting in Abu Dhabi, the CO_2GeoNet Association has been involved in several European policy-related actions concerning CCS, including being an advisor on the European Union's Strategic Energy Technology Plan concerning CCUS with special reference to developing and updating its storage atlas and storage appraisal. It is also helping to define the scope of the 9th European Union Framework Programme for Research and Innovation as it pertains to CCUS. CO_2GeoNet is also one of the reviewers for the second order draft of the Intergovernmental Panel on Climate Change (IPCC) Special Report on the 1.5 degrees scenario. Dr. Wildenborg concluded his presentation by stating that the CO_2GeoNet Association was pleased to accept the invitation to become a Technical Group Allied Organization, and that the Technical Group has been invited to designate a CSLF representative to the CO_2GeoNet Advisory Committee.

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

James Craig, Senior Geologist at the IEAGHG, gave a presentation about the IEAGHG 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. The 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 (320 reports published as of April 2018), the eight international research networks about various topics related to CCS, and the biennial GHGT conferences (the next one in October 2018 in Melbourne, Australia). Other IEAGHG activities include its biennial post combustion capture conferences, its annual International CCS Summer School, 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.

Dr. Craig 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 four IEAGHG studies that originated from the CSLF Technical Group, plus an additional proposed study which became the 2nd International Workshop on Offshore Geologic CO_2 Storage.

Dr. Craig concluded his presentation with a list of reports recently published, reports in progress to be published, studies underway, and studies awaiting start. Dr. Craig also briefly described IEAGHG events, including its webinar series and the upcoming GHGT conference.

9. Update from the Global CCS Institute

John Scowcroft, General Manager for Europe at the Global Carbon Capture and Storage Institute (GCCSI), gave a brief verbal update about the GCCSI. The Institute has recently reorganized on how it operates, having moved away from a regional structure toward more of a global outlook on CCS. 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).

Mr. Scowcroft stated that the GCCSI, in the nine years of its existence, has brought experience, expertise, and resources to help provide its members and stakeholders impactful information which can be used for both policy making and understanding the varied technologies of CCS. In closing, Mr. Scowcroft stated that the GCCSI has at its website many tools and resources about CCS including its "Global Status of CCS" document as well as various reports and fact sheets. Mr. Scowcroft also mentioned that the GCCSI's annual Asia-Pacific CCS Forum would be held in early May, in Shanghai, China, and that there was still time to register for the event.

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

The PIRT Chair, Andrew Barrett, gave a short presentation which summarized the previous day's meeting. Mr. Barrett reported that the meeting was centered on three topics:

- The PIRT has recommended approval by the Technical Group for the Enabling Onshore CO_2 Storage in Europe (ENOS) project in becoming a CSLF-recognized project.
- There was a lively discussion on how to measure progress on recommendations from the TRM.
- There was a discussion on possible Technical Group future activities, as a lead-in to the discussion on that topic in the current Technical Group meeting

Mr. Barrett provided some additional detail about the PIRT's responsibility for measuring progress on recommendations from the TRM. A small working group had been assembled prior to the PIRT meeting and expanded during the meeting to nine PIRT delegates. The expectation is that by the time of the next PIRT meeting, in October, a procedure will have been agreed to on how to accomplish this undertaking, even though some of these recommendations pertain solely to the Policy Group. There is a very strong probability that how much progress toward addressing the TRM recommendations may influence what task forces the Technical Group may decide to form at some point in the future. This, as well as expertise and learnings from CSLF-recognized projects, could be input to the next edition of the TRM.

11. Enabling a Low-Carbon Economy via Hydrogen and CCS (ELEGANCY)

Svend Tollak Munkejord, ELEGANCY project coordinator for SINTEF Energy Research, made a presentation about both SINTEF and the ELEGANCY project. SINTEF is an independent and non-commercial organization, headquartered in Trondheim, Norway, which conducts contract R&D projects. The Energy Research arm of SINTEF provides services both in Norway and globally, which contribute toward the achievement of future sustainable energy systems, for which ELEGANCY is one possible approach.

Dr. Munkejord stated that the context behind ELEGANCY is that a low-carbon economy needs both hydrogen and CCS, so combining hydrogen production with CCS offers opportunities for synergies and value creation. To that end, ELEGANCY aims at contributing toward fast-tracking the decarbonization of the European energy system. The objectives of the project include developing and demonstrating effective CCS technologies with high industrial relevance, identifying and promoting business opportunities for industrial CCS enabled by hydrogen as a key energy carrier, validating key elements of the CCS chain in pilot- and laboratory-scale experiments, de-risking CO_2 storage from hydrogen production by providing experimental data and validated models, providing an open source techno-economic design and operation simulation tool for the full CCS chain including hydrogen as energy carrier, and assessing societal support for key elements of CCS. Dr. Munkejord stated that there would be several country-specific case studies as part of the overall work package, which would be carried out with partner organizations in those countries and will include hydrogen utilization scenarios as well as CCS evaluation. These will be inputs into developing a business case for hydrogen with CCS. The overall budget for ELEGANCY is approximately €15.6 million over the three year project duration, which began in August 2017.

12. Report from the Task Force on Hydrogen Production and CCS "Phase 0" Activities

Task force Chair Lars Ingolf Eide gave a report on the task force, which had been formed at the December 2017 Technical Group meeting in Abu Dhabi. A working group had identified "Hydrogen as a Tool to Decarbonize Industries" as a high priority item for a Technical Group task force, but given that there has been activity in this area by research organizations and industry in several CSLF member countries, the task force had been sanctioned only to gather information on what other organizations have been doing in regards to this topic.

Mr. Eide stated that the task force's investigations covered the future outlook for hydrogen production with CCS as well as how it is presently being implemented in specific parts of the world. Overall, there is expected to be up to a ten-fold increase in hydrogen demand by the year 2050, but there is not yet an economically effective way to produce carbon-free hydrogen in the quantities that will be needed. In Canada, hydrogen production with CCS is currently being implemented in Alberta province at the Quest Project and will also be a part of the under-construction Northwest Sturgeon Project. In China, hydrogen production and CCS are components of several projects, including a coal liquefaction plant and a petroleum refinery. The European Commission is supporting the ELEGANCY project, and there is an evaluation in progress in the Netherlands for converting a natural gas-fueled power plant into a hydrogen-fueled facility with associated carbon capture. Mr. Eide stated that Japan already has a sizeable hydrogen economy including hydrogen-powered fuel cell vehicles, and a natural next step would be to incorporate CCS as a component of hydrogen production. Hydrogen with CCS is also

being investigated for application in Norway and the United Kingdom, while in the United States the large-scale industrial Air Products project has been producing hydrogen with carbon capture (into a pipeline for use as CO_2-EOR) for several years. In addition to all of these, the IEAGHG has been actively investigating the techno-economic evaluation of hydrogen with CCS.

Mr. Eide reported that, in general, the task force's findings are that hydrogen production with CCS is already being implemented and there are few if any technical barriers to CO_2 capture associated with large-scale hydrogen production, but continued research, development and innovation for improved and emerging technologies for clean hydrogen production should be encouraged. Mr. Eide then stated that he did not recommend that the task force continue beyond these "Phase 0" fact-finding activities because there is already much duplicative work in progress, as has been shown by the ELEGANCY presentation. The Technical Group's task force on CCS for Energy Intensive Industries can also include hydrogen production with CCS as one of its areas of interest. Mr. Eide proposed that alternatively, a workshop on hydrogen production with CCS would be useful and that such a workshop could be done in partnership with other organizations such as the IEAGHG.

During ensuing discussion, Andrew Barrett mentioned that Australia also has activities related to hydrogen with CCS with a pilot project producing hydrogen for export from the brown coal deposits in the Gippsland region of Victoria state. There was consensus that the task force not proceed beyond its now-concluded "Phase 0" activities and Mr. Eide was asked to produce a task force report that can be published at the CSLF website. Additionally, the Technical Group will coordinate with allied organizations to hold a workshop on hydrogen with CCS at a future CSLF meeting.

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

Task force Co-Chair Dominique Copin gave a brief update on the task force, which had been established at the October 2016 meeting in Tokyo with a mandate to investigate the opportunities and issues for CCS in the industrial sector and show what the role of CCS could be as a lower-carbon strategy for CO_2-emitting industries. The focus of the task force is to show how CCS in energy intensive industries will contribute to the double target of economic growth and climate change mitigation. Overall, cumulative CO_2 emissions from energy intensive industries are comparable in scale to those from the power generation sector. Mr. Copin reported that the task force consists of members from France's Club CO_2, with additional commitment from Canada, Germany, the Netherlands, Norway, Saudi Arabia, the United Arab Emirates, and the United States. The task force also has commitment from a wide range of professional and technical expertise in the industrial sector including oil and gas (both upstream and downstream), cement, steel, hydrogen, chemicals, fertilizer, and waste-to-energy.

Mr. Copin stated that relevant issues being examined include: why CCS for industry is an important issue, which industries and their emissions to focus on, what potential alternatives to CCS exist (if any) to achieve zero CO_2 emissions for different industries, and the status of CCUS developments from laboratory scale to industrial demonstration. Task force findings are that for most energy intensive industries, a significant part of CO_2 emissions are due to the process itself and not to fossil fuel consumption. Usage of renewable energy for many industries therefore cannot be regarded as an alternative to CCS in terms of reducing CO_2 emissions from those industries. Business models for

developing CCS will have to be developed by these industries, which may require support of government.

Mr. Copin concluded his presentation by stating that the task force has completed much of its work and that draft versions of most chapters in its final report have been prepared. The target is to have the final report complete in time for the 2018 CSLF Annual Meeting in October.

14. Report from the Bioenergy with CCS (BECCS) Task Force

Task force Chair Mark Ackiewicz gave a brief update on the task force, which was established at the November 2015 meeting in Riyadh and has now completed its activities. Task force members included the United States as lead, Norway, the United Kingdom, and the IEAGHG. Mr. Ackiewicz stated that the task force's final report has been completed and was included in the documents for the current meeting. The report includes an executive summary and introductory chapter as well as chapters which provide a summary of resource assessments and emissions profiles, the commercial status of BECCS technology development, and an overview of BECCS technology options and pathways.

Mr. Ackiewicz summarized task force findings. There are currently many barriers for BECCS and progress is needed in several key areas: technical, economic, resource limitations, policy / regulation, and supply chain development. There were ten recommendations:

- R&D is needed to develop and identify biomass feedstocks that require limited processing;
- Optimization is needed for biomass feedstock water use and the carbon footprint;
- Availability of biomass feedstocks should be monitored on a regional basis;
- Biomass pre-treatment processes (densification, dehydration, pelletization) need improvement;
- Technologies with lower costs and energy penalties need to be identified and developed;
- A common framework for lifecycle assessment should be developed in order to facilitate accurate accounting of the BECCS carbon footprint;
- Policy makers should be informed with respect to the benefits of BECCS market opportunities;
- There is a need to build trust with public and local communities;
- Stronger collaboration is needed between CCUS stakeholders, bioenergy, and BECCS industries; and
- There is a need to financially incentivize the double benefit of BECCS.

Mr. Ackiewicz closed his presentation by stating that the task force had concluded its activities. There was consensus by the Technical Group to disband the task force.

15. Report from the Improved Pore Space Utilisation Task Force

Task force Co-Chair Max Watson gave a brief update on the task force, which was 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. Dr. Watson stated that the purpose of the task force is to investigate the concept of improved utilisation of geological storage space resource to

increase CO_2 storage capacity, review the current state of processes and technologies that enhance utilisation of the storage space, highlight key techniques that have recently emerged internationally, and provide a set of options for stakeholders to develop into their CO_2 storage projects. With straightforward CO_2 injection, in particular when storing in saline formations, a large portion of available pore space in a geological storage site is bypassed. Utilized storage capacity is typically about two orders of magnitude lower than the pore space resource, and the resulting large lateral spread of CO_2 requires costly monitoring relative to the volume stored. Being able to improve pore space utilisation may be very beneficial in terms of increased storage capacity, reduced monitoring costs, and increased ability for 'hub' style storage operations.

Dr. Watson stated that the task force's final report would include seven topics related to pore space utilisation: oil & gas literature review, non-technical issues related to improved pore space utilisation, pressure management, microbubble injection, CO_2 saturated water injection & geothermal energy production, compositional & temperature swing injection, and technique effectiveness. Work is complete on all topics except for the technology effectiveness section, which will be finished soon. Dr. Watson concluded his presentation by stating that the task force timeline now shows the final report being complete by August 2018 and it will be part of the documents book for the 2018 CSLF Annual Meeting in Melbourne.

16. Review and Approval of Project Proposed for CSLF-Recognition: Enabling Onshore CO_2 Storage in Europe (ENOS)
(nominated by Italy [lead], Australia, Canada, France, the Netherlands, Norway, Romania, and the United Kingdom)

Marie Gastine, representing BRGM and the CO_2GeoNet Association, gave an overview presentation about the ENOS project. This is a multi-faceted project whose objectives are to provide crucial advances to help foster onshore CO_2 storage in Europe through (a) developing, testing and demonstrating key technologies specifically adapted to onshore storage, and (b) contributing to the creation of a favorable environment for onshore storage across Europe. The European Union-funded project considers Europe in a broad context, though research will mainly be based on data from the Hontomin pilot site in Spain, two oil and gas fields in the Netherlands and the Czech Republic, and two field laboratories where CO_2 leakage will be simulated. Overall, ENOS has 29 partner research organizations located in 17 countries throughout Europe. Project activities include CO_2 injection testing in order to validate technologies related to reservoir monitoring, preservation of potable groundwater and terrestrial/aquatic ecosystems, and detection of any CO_2 leakage. In addition, the project will lead to increased data availability for improved site characterization and increased understanding and prevention of induced seismicity (which is crucial in an onshore storage context). The project also has a goal of integrating onshore CO_2 storage with local economic activities and of engaging researchers with local communities.

After a brief discussion, there was consensus to recommend to the Policy Group that the project receive CSLF recognition.

17. Update on Mitsubishi's KM CDR Process and Experience

Takashi Kamijo, Chief Engineering Manager for CO_2-EOR Business Development at Mitsubishi Heavy Industries (MHI), gave a presentation which described MHI's amine-based Kansai Mitsubishi Carbon Dioxide Removal (KM CDR) process and its application

in industry and power generation. The process utilizes a proprietary hindered amine solvent which has the benefits of low energy, low solvent degradation and negligible corrosion. The process also features a proprietary heat recovery system, a deep amine emission reduction system, and an automatic load adjustment system. There are currently 13 commercial KM CDR installations worldwide of at least 200 tonnes CO_2 capture per day, plus one installation of 1,200 tonnes CO_2 capture per day that is under construction. The largest of these is the Petra Nova Project, near Houston, Texas in the United States, which has a CO_2 capture capacity of 4,776 tonnes per day, from a coal-fueled power generation unit at the W.A. Parish Generating Station. This installation is currently the world's largest power plant-based carbon capture project.

Mr. Kamijo described the KM CDR process as being commercial since 1999 with most of the installations at urea production facilities. The process has seen use with various flue gas sources (natural gas, heavy oil, and coal), and that CCUS has been the main driver for the commercial projects where it is in use. There have so far been two KM CDR Users' Conferences (the most recent in 2015 in Bahrain) where operation experiences have been shared, with lessons learned being used to improve the process. Mr. Kamijo concluded his presentation by briefly describing the ongoing effort by MHI Engineering to further improve the process. These include reducing the cost of capturing CO_2 through technical improvements which will increase efficiency and reduce solvent degradation.

18. Results from CSLF-recognized Projects: Zama Project and Fort Nelson Project

James Sorensen, Principal Geologist at the University of North Dakota's Energy and Environmental Research Center (EERC), gave a presentation about two CSLF-recognized projects located in western Canada. The Zama Acid Gas EOR, CO_2 Sequestration and Monitoring Project, located in northern Alberta province, was a pilot-scale project which utilized acid gas (approx. 70% CO_2 and 30% hydrogen sulfide) derived from natural gas extraction for enhanced oil recovery. A total of 85,000 tonnes was injected over the duration of the project. Objectives were to predict, monitor, and evaluate the fate of the injected acid gas; to determine the effect of hydrogen sulfide on CO_2 sequestration; and to develop a "best practices manual" for measurement, monitoring, and verification of storage (MMV) of the acid gas. Additional goals were to assess and quantify the uncertainties associated with existing data in order to help CO_2 storage from operational and planning standpoints, to provide insight regarding the design of the CO_2 storage scheme, and to obtain an improved estimate of the recoverable oil resource and associated storage. Mr. Sorensen stated that a key conclusion from the project was that the presence of hydrogen sulfide in the EOR gas stream can lower the minimum miscibility pressure which results in an overall improvement by lowering the cost of injection, though process modifications and specialized equipment are required to ensure safety and minimize corrosion. Additionally, two other conclusions were that so-called geologic "pinnacle reefs", such as the ones utilized by this project, are great candidates for CO_2 storage, and "sour" CO_2 can be safely and economically used for geologic storage and CO_2-EOR.

The Fort Nelson CCS Project, located in northern British Columbia province, had the objective of developing a feasibility study for a large natural gas-processing plant for CCS into deep saline formations of the Western Canadian Sedimentary Basin (WCSB). Goals of the project were to verify and validate the technical and economic feasibility of using brine-saturated carbonate formations for large-scale CO_2 injection and show that robust monitoring, verification, and accounting (MVA) of a brine-saturated CO_2 sequestration project can be conducted cost-effectively. The feasibility study incorporated a risk-based approach to define the MVA strategy, modeling and simulation, site characterization, risk

assessment, and development of a cost-effective MVA plan. Mr. Sorensen stated that there was a 50-year injection scenario with three injection wells and up to 2.5 million tonnes injection per year of CO_2 captured from a nearby gas-processing facility. For this, the recommended MVA regime included shallow groundwater monitoring wells near to where the injection wells were located, surface water sampling from lakes and rivers in the vicinity of the project, soil gas monitoring, and four deep monitoring wells. Mr. Sorensen stated that, in the end, CCS at Fort Nelson has been put on hold until a business case can be made, but the site has excellent potential for CO_2 storage. A key conclusion from the project was that an integrated approach to site characterization, modeling, and risk assessment can lead to an effective site-specific monitoring program, identify data gaps in site characterization, and increase the likelihood of project success by identifying and mitigating project risks. Mr. Sorensen closed his presentation by stating that both the Zama and the Fort Nelson Projects have been concluded.

19. Results from CSLF-recognized Project: Norcem Carbon Capture Project

Liv Bjerge representing project sponsor HeidelbergCement was not able to attend the meeting so Lars Ingolf Eide instead gave her presentation about the now-concluded Norcem Carbon Capture Project. This project, located in southern Norway at a commercial cement production facility, conducted testing of four different post-combustion CO_2 capture technologies at scales ranging from very small pilot to small pilot. Project partners were Norcem, HeidelbergCement, and the European Cement Research Academy, and technologies evaluated were a 1st generation amine-based solvent, a 3rd generation solid sorbent, 2nd generation gas separation membranes, and a 2nd generation regenerative calcium cycle, all using cement production facility flue gas. Objectives of the project were to determine the long-term attributes and performance of these technologies in a real-world industrial setting and to learn the suitability of such technologies for implementation in modern cement kiln systems. Focal areas included CO_2 capture rates, energy consumption, impact of flue gas impurities, space requirements, and projected CO_2 capture costs.

Ms. Bjerge's presentation provided some results as well as lessons learned from the project. Testing the four technologies under real-world conditions, even at pilot scale, turned out to be extremely useful and overall, the project was deemed a success even though not all results were as expected. There were some difficulties in design for scaling up one of the processes from bench scale to pilot, and two of the technologies did not mature in terms of technology readiness level. The only technology supplier which managed to deliver a full-scale design including economic calculations was Aker Solutions, whose capture process was deemed to be the most mature of those tested. A project outcome was that the quality of results was highly dependent on the quality of the pilot facilities, with the conclusion that a commercial partner is of utmost importance for any technology that is being advanced toward commercialization. The most important and perhaps most obvious lesson learned is that conducting an aggressive pilot program of this nature almost always takes more time and resources than originally anticipated, so that should be factored into any test program. The Norcem Carbon Capture project has been of great importance for the proposed Norwegian full scale project, where CCS on a cement production facility is one of the three options.

20. Results from CSLF-recognized Project: CO_2 Capture Project Phase 4 (CCP4)

Mark Crombie, representing project sponsor BP, provided an overview of the CO_2 Capture Project, which has an overall goal of advancing CCS technology deployment and

knowledge for the oil and gas industry. Phase 1 of the project, which ran from 2000 through 2004, concentrated on technology screenings through proof of concept. Phase 2, which ran from 2004 through 2009, featured intensive development of these technologies. Phase 3, which ran from 2009 through 2014, was the demonstration phase for these technologies. Phase 4, which began in 2014 and is scheduled to end in 2020, is focused on further advancement of these technologies.

Mr. Crombie described some of the results from CCP4. The purpose of Phase 4 is to increase the understanding of existing, emerging, and breakthrough CO_2 capture technologies and target a reduction in CO_2 capture cost by greater than 30%. To do this, CCP4 is supporting small- and pilot-scale techno-economic studies for four scenarios: refinery production, natural gas combined cycle, natural gas extraction, and heavy oil. In addition, specific studies are ongoing to assess two advanced solvent processes which are in different stages of development and to explore the techno-economic feasibility of CO_2 capture from small-scale natural gas-fueled engines. CCP4 also features a program component for ensuring safe and effective long-term CO_2 storage, with RD&D to address key CO_2 storage uncertainties and risks and a strategy which includes identifying key gaps in CO_2 storage assurance, developing projects with key third-party researchers to address these gaps, progressing these projects through technology readiness levels with an aim toward field testing of selected technologies and rapid publication of results. Mr. Crombie closed his presentation with short descriptions of two other CCP4 components: including policy / incentives and communications. The former is intended to assist the development of legal and policy frameworks through project experiences in the regulatory process, while the latter assists the sharing of the CO_2 Capture Project's work and expertise.

21. Optimizing the Work of the Academic Task Force with the Technical Group

Sallie Greenberg gave a short presentation about the CSLF's Academic Council which was established by the CSLF Task Force following the 2015 CSLF Ministerial Meeting. The Academic Council comprises representatives from institutes and universities in CSLF member countries and serves in an advisory capacity to the Academic Task Force. The first meeting of the Academic Council was held in June 2016 as part of the CSLF Mid-Year Meeting in London. Dr. Greenberg stated that the Academic Council has three main focal areas: student training, practical learning and curriculum development; communication and outreach; and academic community and capacity building. The goals are to identify academic research linkages with CSLF Technical Group and Policy Group priorities; to determine where and how the CSLF can help leverage international collaborations, student exchanges, networks and funding opportunities to further CSLF goals; and to develop an overall plan of action. Dr. Greenberg reported that all of these focal areas have their own specific goals and objectives, and the Academic Council's activities in these areas have resulted in sets of recommendations.

Dr. Greenberg concluded her presentation by describing four recommendations for the Technical Group's consideration:

- Consider opportunities for research and capacity building through Technical Group member countries and organizations;
- Leverage existing synergies between the Academic Task Force, the CSLF Technical Group, Mission Innovation, and other organizations in order to advance the opportunities for CCUS deployment;

- Consider mechanisms to distill and disseminate technical research by the Technical Group member countries for high-level communication with the Policy Group, the Clean Energy Ministerial, and ministerial-level organizations; and
- Further engage and explore connections for the Academic Council to support Technical Group and Policy Group connections.

Ensuing discussion brought forth the idea that a survey could be sent to Academic Council members to see how much, if any, benefit the Technical Group's task force reports on various topics is to the general academic community in terms of informational value for both students and professors. There was consensus that this was a good idea, but further discussion was postponed until the agenda item on possible new Technical Group activities (see below).

22. Update from the Mission Innovation Carbon Capture Innovation Challenge (CCIC)

Tidjani Niass gave a short presentation about Mission Innovation and its CCIC. Mission Innovation is a Ministerial-level initiative that was launched in November 2015 at the Paris climate meeting and currently includes 22 countries plus the European Commission. Collectively, these countries represent 60% of the world's population, 70% of the global GDP, 80% of worldwide government investment in clean energy RD&D, and 67% of the total world greenhouse gas emissions. The overall goal of the Mission Innovation initiative is to accelerate 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' investment in clean energy (from $15 billion to $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.

Dr. Niass stated that the overall objective for the CCIC 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. A CCIC Experts Workshop, co-chaired by the United States and Saudi Arabia, was held in 2017 and focused on establishing the current state of technology in CCUS, identifying and prioritizing R&D gaps and opportunities, and establishing high priority research directions to address opportunities. Dr. Niass stated that the Workshop was a success, with 22 countries participating and a total of 257 participants representing government, academia, and industry. There were three main focus areas: CO_2 capture, CO_2 utilization, and CO_2 storage. In addition to these, a separate group was focusing on crosscutting issues. Each of these focal areas developed a set of international agreed priority research directions (PRDs), which were summarized in the report "Accelerating Breakthrough Innovation in Carbon Capture, Utilization, and Storage" dated September 2017. Dr. Niass stated that the PRDs are not meant to be prescriptive and all-inclusive. Instead, they were designed to inspire the CCUS research community to elucidate and illuminate the science that underpins CCUS. Dr. Niass concluded his presentation by providing the next steps for the CCIC. These include delivering a report of CCIC activities at the upcoming 3rd Mission Innovation Ministerial (in May 2018), developing collaboration mechanisms, and fostering engagement with industry and other multilateral CCUS initiatives, including the CSLF.

23. Update from Working Group on Evaluating Existing and New Ideas for Possible Future Technical Group Actions

In follow-up to one of the outcomes from the December 2017 Technical Group meeting, Paul Ramsak gave a presentation about CO_2 capture and storage by mineralization, which had been one of the priority topics identified by a Technical Group working group which had been formed in 2017 to appraise all unaddressed items in the Technical Group's 2015 Action Plan, to propose new topics for appraisal, and to review past task force reports to see if any updates are warranted. Mr. Ramsak provided a short primer on the topic, stating that CO_2 capture and storage by mineralization is a niche opportunity for creating bulk construction and landscaping materials that could substitute for existing materials such as sand and gravel. In particular, accelerated binding processes use CO_2 to react with a range of minerals to form carbonates such as calcite and magnesite. In some cases, CO_2 becomes a new or substitute feedstock for concrete production, or sees use for curing or otherwise processing cement. Work on accelerated binding processes in the Netherlands, Germany, and the United Kingdom in recent years have resulted in its technology readiness level being improved. In particular, the United Kingdom's Carbon8 Project has three full-scale production facilities where CO_2 is being utilized to convert thermal wastes into building aggregates. In spite of these promising advances, Mr. Ramsak concluded his presentation by stating that it was nevertheless too early for the Technical Group to create a task force on CO_2 mineralization. Instead, it would be better to revisit and update the report from the Task Force on CO_2 Utilization, in particular the sections about non-EOR utilization options. This would result in a more useful input to the next iteration of the CSLF TRM. During brief ensuing discussion, there was consensus by the Technical Group to not form a new task force in this area.

Technical Group Chair Åse Slagtern then made a short presentation that summarized existing Technical Group activities and possible new ones. There are now only two active task forces besides the PIRT: Improved Pore Space Utilization (co-chaired by Australia and the United Kingdom) and CCS for Energy Intensive Industries (chaired by France). Ms. Slagtern stated that there are 24 potential new topics: eleven remaining from the original list of possible actions, eleven past task force topics which might merit update, and two new proposals. The members of the working group participated in a preference poll, which resulted in a shortlist of twelve topics and a "final four" of highest ranked topics:

1. Hydrogen as a Tool to Decarbonize Industries (which was the clear winner)
2. Reviewing Best Practices and Standards for Geologic Monitoring and Storage of CO_2
3. CO_2 Capture by Mineralization
4. Global Scaling of CCS

Of these, there had already been a consensus not to continue the Hydrogen Production and CCS as a task force and instead follow-up with a workshop. Also, there had been a consensus not to form a task force on CO_2 Capture by Mineralization. However, during ensuing discussion there was interest in following up on Mr. Ramsak's suggestion to revisit the topic of non-EOR CO_2 utilization, with the caveat that it should not be duplicative of similar studies done by other organizations. The Technical Group's Task Force on Utilization Options for CO_2 had been active between 2011 and 2013 and had produced two reports (which are archived at the CSLF website). There was consensus to re-form that task force to examine non-enhanced hydrocarbon recovery CO_2 utilization options, with the United States as Chair and participation from Australia, Canada, France

(pending endorsement by its Club CO_2), the Netherlands, and Saudi Arabia. The Task Force was requested to develop a plan and timeline to be presented at the next Technical Group meeting.

Discussion then resumed from the previous day's PIRT meeting on how to measure progress on recommendations from the TRM. The PIRT had reached consensus that the details for moving forward in this area were not solvable at the current meeting but that the Secretariat would moderate an offline discussion for any delegates who wanted to have a role. However, there was consensus that this should instead be a full Technical Group activity, as there was interest in also evaluating the present form of Technical Group task forces as well as alignment with the CSLF Academic Task Force and Communications Task Force. Sallie Greenberg volunteered to take the lead in organizing an informal group to determine what can be done in this area and how to do it. This could include a survey of some kind and also participation from outside organizations such as Mission Innovation and other CCUS organizations. Progress, including a proposed way forward, will be reported at the next Technical Group meeting.

24. Update on Future CSLF Meetings

Richard Lynch stated that there was nothing yet to report about the 2019 CSLF meetings and that expressions of interest in hosting a meeting would be welcome. Max Watson reported that the 2018 Annual Meeting would be held in Melbourne, Australia on 16-18 October, which is the week prior to the IEAGHG's GHGT conference. The PIRT meeting would be on Tuesday, October 16th, the Technical Group meeting on Wednesday, October 17th, and the Policy Group meeting on Thursday, October 18th. Additional details would also be forthcoming soon.

25. Open Discussion and New Business

Three of the four CSLF regional stakeholder engagement leads were in attendance and presented brief reports. Pieter Smeets, representing the Middle East / Africa region, stated that holding a stakeholder workshop was beneficial and that the next workshop for that region would not occur until the roll-up period for the next CSLF Ministerial meeting. Jiro Tanaka, representing the Asia / Pacific region, stated that a stakeholder survey was done prior to the 2017 CSLF Ministerial and that results were summarized into a report. To maximize regional stakeholder participation, this approach will be continued for the roll-up to the next Ministerial. Ton Wildenborg, representing the Europe region, stated that an active group of European stakeholders is being assembled to send clear messages about CCS and its technologies to decision makers in the European Commission, and that a regional stakeholder meeting will be held about every two years.

David Savary reported that a symposium titled "International Overview of CO_2 Utilisation" is being hosted by France's Club CO_2 on July 2nd in Paris. The Symposium is being organized with two themes: "International Status of Carbon Capture and Utilization (CCU)" which will have a wide overview of global developments about CO_2 utilization, and "Which tools to enhance CCU?" whose focus will be on exchange among participants on standardization and life cycle assessment as levers for deployment of CCU.

Paolo Deiana mentioned that the Sixth Annual Sulcis CCS Summer School will be held on June 18-22 at the Sotacarbo Research Centre on Italy's Sardinia Island. Lectures during the five days of the event will cover the range of technologies developed for capture, utilization, and geologic storage of CO_2, for which the Sulcis basin is an ideal

laboratory for experiments. The summer school is intended for PhD and Postdoctoral students in engineering curricula and social aspects relevant to CCS.

Brian Allison stated that the United Kingdom CCS Research Centre's Pilot-Scale Advanced CO_2 Capture Technology (PACT) facility is now the lead for the International Test Center Network (ITCN). There was consensus that a presentation about the ITCN be included in the next Technical Group meeting.

26. Closing Remarks / Adjourn

Technical Group Chair Åse Slagtern thanked the delegation from Italy for hosting the meeting, the CO_2GeoNet Association for its help in arranging the meeting's venue and logistics, the Secretariat for its pre- and post-meeting support, and the delegates for their active participation. She then adjourned the meeting.

Summary of Meeting Outcomes

- The ENOS project is recommended by the Technical Group to the Policy Group for CSLF recognition.
- The Task Force on Hydrogen with CCS will not continue beyond its now-completed "Phase 0" activities. Instead, a workshop on Hydrogen with CCS will be organized for a future CSLF meeting. A report on the task force's "Phase 0" findings will be published at the CSLF website.
- The CCS for Energy Intensive Industries Task Force and the Improved Pore Space Utilisation Task Force will present their final reports at the next Technical Group meeting.
- The BECCS Task Force has submitted its final report and has disbanded.
- The Technical Group will not form a new task force on CO_2 Capture and Storage by Mineralization, as it was deemed premature to do so.
- The Technical Group has formed a task force to examine non-EOR CO_2 utilization options, which will develop a plan and timeline to be presented at the next Technical Group meeting. Task force members are the United States (Chair), Australia, Canada, France, the Netherlands, and Saudi Arabia.
- Follow-up on recommendations from the 2017 TRM is now a full Technical Group activity instead of being assigned to the PIRT. This activity will also include measuring the use of Technical Group task forces as well as alignment with the CSLF Academic Task Force and Communications Task Force. United States delegate Sallie Greenberg will organize an informal group to determine what can be done. Progress, including a proposed way forward, will be reported at the next Technical Group meeting.
- A presentation about the ITCN will be included in the next Technical Group meeting.