carbon sequestration leadership forum

2014 CSLF

Technical Group Meeting

Seoul, Korea

March 24-27, 2014

Carbon Sequestration Leadership Forum

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CSLF Technical Group Meeting
and
Technology Workshop

Seoul, Korea
24-27 March 2014

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CSLF-T-2014-01
Draft: 18 March 2014
Prepared by CSLF Secretariat

DRAFT AGENDA
CSLF Technical Group Meeting
Renaissance Seoul Hotel
Seoul, Korea
March 25, 2014

09:00-10:45 **Technical Group Meeting**
Diamond I & II Rooms

1. **Welcome and Opening Statement**
   Trygve Riis, Technical Group Chair, Norway
2. **Host Country Welcome**
   Ki Young Park, Director General for Energy Efficiency & Climate Change Bureau, Ministry of Trade, Industry and Energy (MOTIE), Korea
3. **Introduction of Delegates**
   Delegates
4. **Adoption of Agenda**
   Trygve Riis, Technical Group Chair, Norway
5. **Review and Approval of Minutes from Washington** CSLF-T-2013-10
   Trygve Riis, Technical Group Chair, Norway
6. **Review of Washington Meeting Action Items**
   Richard Lynch, CSLF Secretariat
7. **Report from Secretariat**
   - Secretariat Updates
   - Report on CSLF Activities
   - CSLF Recognized Projects Report

   Richard Lynch, CSLF Secretariat
8. **CCS in Korea**
   Hocheol Kim, Director, GHG Reduction Team, MOTIE, Korea
9. **Update from the IEA Greenhouse Gas R&D Programme**
   Tim Dixon, IEA GHG
10. **Update from the Global CCS Institute**
    (presented by) Clinton Foster, PIRT Chair, Australia

10:45-11:00 **Refreshment Break**
Foyer outside Diamond I & II Rooms

11:00-12:30 **Continuation of Meeting**

11. **Report from Projects Interaction and Review Team**
    Clinton Foster, PIRT Chair, Australia
12. **Update Plan for CSLF Technology Roadmap**
    Clinton Foster, PIRT Chair, Australia

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13. Report from Review of CO_2 Storage Efficiency in Deep Saline Aquifers Task Force
Stefan Bachu, Task Force Chair, Canada

14. Report from Reviewing Best Practices and Standards for Geologic Storage and Monitoring of CO_2 Task Force
Lars Ingolf Eide, Task Force Chair, Norway

15. Report on Barriers and Technical Needs for Sub-Seabed Storage of CO_2 CSLF-T-2014-02
Mark Ackiewicz, United States

16. Analysis of IEA GHG Report on Interaction of CO_2 Storage with Subsurface Resources
Didier Bonijoly, France

17. Appraisal of Proposed Technical Group Actions concerning CCS with Industrial Emissions Sources
Tony Surridge, South Africa

18. Appraisal of Proposed Technical Group Actions concerning Energy Penalty Reduction and Carbon Neutral / Carbon Negative CCS
Philip Sharman, United Kingdom

19. Appraisal of Proposed Technical Group Actions concerning Lifecycle Assessment and Environmental Footprint of CCS
Lars Ingolf Eide, Norway

20. Appraisal of Proposed Technical Group Actions concerning CO_2 Compression and Transport
Ryozo Tanaka, Japan

12:30-13:30 Lunch
Topaz Room (4th floor) or TBA

13:30-15:00 Continuation of Meeting

21. Roundtable Event:
CCS Technologies and Projects for Emerging Economies
Participants:
TBA, Brazil (invited)
Jiutian Zhang, China
Edgar Santoyo-Castelazo, Mexico
Tony Surridge, South Africa

Moderator:
Ashok Bhargava, Director, Energy Division, Asian Development Bank

15:00-15:15 Refreshment Break
Foyer outside Diamond I & II Rooms

15:15-16:30 Continuation of Meeting

22. Status of Technical Group Action Plan / Formation of New Task Forces CSLF-T-2014-03
Trygve Riis, Technical Group Chair, Norway

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23. Possibilities for Collaboration with CSLF Policy Group CSLF-T-2014-04
Trygve Riis, Technical Group Chair, Norway

24. New Business
Delegates

25. Action Items and Next Steps
Richard Lynch, CSLF Secretariat

26. Closing Remarks / Adjourn
Trygve Riis, Technical Group Chair, Norway

18:00-21:00 **Reception / Dinner**
Suraon Restaurant *(118-3, Banpo-dong, Seocho-gu, Seoul 037-040)*

Note: This document may not be available in printed form at the meeting. Please print it prior to the meeting if you need a hardcopy.

Carbon Sequestration Leadership Forum
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2014 CSLF Technology Workshop
Seoul, Korea
26 March 2014

09:00-09:15
Plenary Session

Workshop Introduction and Background
Richard Lynch, CSLF Secretariat

Welcoming and Keynote Address
Byung-Sook Kim, CTO, New Growth Engine Division, KEPCO, Korea

09:15-12:00
Session 1: Cost Reduction Strategies for CO_2 Capture

Session Co-Chairs:
Mark Ackiewicz, United States
Philip Sharman, United Kingdom

This session will review existing CO_2 capture cost reduction strategies taken by projects and governmental programs and initiatives. The panel will discuss the effectiveness of these existing strategies and suggest possible new ideas for reducing the cost of CO_2 capture for large-scale projects.

- **National Carbon Capture Center**
  Frank Morton, Southern Company Services, United States
- **Hadong and Boryeong Pilot Projects**
  Chong Kul Ryu, KEPCO RI, Korea
- **Energy and Environmental Research Center's Economic Case for CCUS by Reducing Capture Costs**
  John Harju and Edward Steadman, Energy and Environmental Research Center, United States
- **CO_2 Technology Centre Mongstad Project**
  Lars Ingolf Eide, Research Council of Norway

Messages and Takeaways from Session
Session Co-Chairs

12:00-13:00
Lunch
Location TBA

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13:00-16:00

Session 2: Examining Technology Pathways and Business Models for Scaling-up CCS

Session Co-Chairs:

Chang Keun Yi, Korea

Richard Aldous, Australia

This session will discuss the unique challenges in establishing technology pathways and business models for transitioning CCS to commercial scale. The panel will examine several key aspects in integrating diverse components (capture, transport and storage) of major CCS projects and establishing strategies and baselines that make sense from a business plan perspective.

- **SaskPower Integrated CCS Demonstration Project at Boundary Dam Unit 3**
  Michael Monea, Saskatchewan Power Corporation, Canada
- **Chinese Pathways toward Demonstration and Deployment**
  Jiutian Zhang, ACC21, China
- **Financial Institute Perspectives**
  Annika Seiler, Energy Division, Asian Development Bank

Messages and Takeaways from Session

Session Co-Chairs

Workshop Concept

- Following presentations, there will be a discussion among the panelists facilitated by the session co-chairs.
- Following the panelist discussion, there will be an Audience Interaction Q&A session.

Carbon Sequestration Leadership Forum

Prepared by CSLF Secretariat

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Agenda

CSLF PROJECTS INTERACTION AND REVIEW TEAM (PIRT)

Renaissance Seoul Hotel
Seoul, Korea
24 March 2014

Jade Room
14:00-16:00

1. **Welcome and Opening Remarks**
   Clinton Foster, PIRT Chair, Australia
2. **Introduction of Attendees**
   Meeting Attendees
3. **Approval of Summary from Washington PIRT Meeting**
   Clinton Foster, PIRT Chair, Australia
   Richard Lynch, CSLF Secretariat
4. **Update on PIRT Membership**
   Clinton Foster, PIRT Chair, Australia
5. **Knowledge-Sharing from CSLF-Recognized Projects**
   Clinton Foster, PIRT Chair, Australia
6. **Update Plan for CSLF Technology Roadmap**
   Clinton Foster, PIRT Chair, Australia
   PIRT Members
7. **Development of PIRT Action Plan**
   Clinton Foster, PIRT Chair, Australia
   PIRT Members
8. **Closing Comments / Adjourn**
   Clinton Foster, PIRT Chair, Australia

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CSLF Technical Group Meeting
Seoul, Korea
24-27 March 2014

	Monday **24 March** **Renaissance Seoul Hotel**	**Tuesday** **25 March** **Renaissance Seoul Hotel**	**Wednesday** **26 March** **Renaissance Seoul Hotel**	**Thursday** **27 March** **Daejeon**
Morning	Meeting Registration *Foyer outside Jade Room* *10:00-17:00*	Meeting Registration *Foyer outside Diamond Rooms* *08:00-09:00* CSLF Technical Group *Diamond I & II Rooms (3rd floor)* *09:00-12:30*	**TECHNOLOGY WORKSHOP** Plenary Session *Diamond I Room* *09:00-09:15* Session 1: Cost Reduction Strategies for CO_2 Capture *Diamond I Room* *09:15-12:00*	Technical visit to Hadong and Boryeong Pilot Plants *Bus departs from hotel in Daejeon at 07:00*
		Lunch *Topaz Room (4th floor)* *12:30-13:30*	Lunch *12:00-13:00*	Lunch
Afternoon	CSLF Projects Interaction and Review Team (PIRT) *Jade Room (4th floor)* *14:00-17:00*	CSLF Technical Group *Diamond I & II Rooms* *13:30-16:30*	**TECHNOLOGY WORKSHOP** Session 2: Examining Technology Pathways and Business Models for Scaling-up CCS *Diamond I Room* *13:00-16:00*	Technical visit to Hadong and Boryeong Pilot Plants *Bus returns 20:30*
Evening	Reception / Dinner *TBA (Japanese restaurant adjacent to hotel)* *18:00-20:00*	Reception / Dinner *Suraon Restaurant* *18:00-21:00* *(transportation provided)*	***Transit to Daejeon by bus.*** ***NOTE: Technical visits on 27 March depart from Hotel Yousung in Daejeon.***	

Meeting documents will be available only electronically. Please print them prior to the meeting if you need hardcopies.

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Technology Site Visits Information Sheet

Korea currently sponsors two post-combustion CO_2 capture pilot plants. The 10-MW facility at Hadong Power Plant utilizes dry regenerable sorbent technology, while the 10-MW facility at Boryeong Power Plant utilizes an advanced amine sorbent. On March 27, attendees of the 2014 CSLF Technical Group meeting will have the opportunity to visit both of these pilot plants.

Following the conclusion of the March 26 Technology Workshop, everyone participating in the on March 27 Technology Site Visits will depart approx. 17:00 from the Renaissance Seoul Hotel and travel to the Yousung Hotel in Daejeon (about 2 hours transit time). Transportation, by bus, has been arranged. Upon arrival and check-in, there will be a dinner at a restaurant in Daejeon.

You do not need to make a reservation at the Yousung Hotel. This will be done for you by our meeting hosts. However, you will be responsible for the cost of the room in Daejeon. A special room rate of 100,000 KWN has been arranged.

<u>Technology Site Visits itinerary for Thursday, March 27</u>

07:00	Depart Yousung Hotel (by bus)
10:00	Arrive at Hadong Thermal Power Station
10:00-11:30	Technology tour of Hadong Thermal Power Station
11:30	Depart Hadong Thermal Power Station
12:00-13:00	Lunch at local restaurant
13:00	Depart for Boryeong
16:00	Arrive at Boryeong Thermal Power Station
16:00-17:30	Technology tour of Boryeong Thermal Power Station
17:30	Depart Boryeong Thermal Power Station
18:00-19:00	Dinner at local restaurant
19:00	Depart Boryeong
20:30	Arrive atYousung Hotel in Daejeon

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We recommend that you make your airline departure reservations for Friday, March 28. Information on transit options to Incheon International Airport and Gimpo International Airport from Daejeon are as follows:

Express shuttle buses run from Daejeon to the two airports. Taxi fare from the Yousung Hotel to the shuttle bus station (20 minute ride) will be approx. US$10.

Shuttle buses to **Incheon International Airport** run from about 03:30 to 19:30 each day. **Transit time is approx. 3 hours**, and fare is approx. US$30. The bus schedule is as follows:

03:29-05:36: every 10 minutes
05:36-08:56: every 20 minutes
08:56-11:16: every 30 minutes
11:16-15:16: every 20 minutes
15:16-18:16: every 30 minutes
18:16-18:36: every 20 minutes
18:36-19:26: every 10 minutes

Shuttle buses to **Gimpo International Airport** run from about 07:30 to 19:30 each day. NOTE: Gimpo has flights **only** to Tokyo, Osaka, Beijing, Shanghai, and Taipei. **Transit time is approx. 2¾ hours**, and fare is approx. US$30. The bus schedule is as follows:

Depart Daejeon	Arrive Kimpo
07:26	10:10
08:26	11:10
10:16	13:00
11:26	14:10
13:06	15:50
15:06	17:50
16:36	19:20
19:46	22:30

Draft

Carbon Sequestration Leadership Forum

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CSLF-T-2013-10
Draft: 06 January 2014
Prepared by CSLF Secretariat

DRAFT

Minutes of the Technical Group Meeting

Washington, D.C., USA
Tuesday, 05 November 2013

LIST OF ATTENDEES

Chair	Trygve Riis (Norway)

Technical Group Delegates

Australia:	Clinton Foster (Vice Chair), Richard Aldous
Canada:	Stefan Bachu (Vice Chair), Eddy Chui
China:	Jiutian Zhang, Sizhen Peng
European Commission:	Jeroen Schuppers, Stathis Peteves
France:	Didier Bonijoly
Italy:	Giuseppe Girardi
Japan:	Ryozo Tanaka
Korea:	Chang-Keun Yi, Chong Kul Ryu
Mexico:	Javier Flores, Moisés Dávila
Netherlands:	Paul Ramsak
Norway:	Jostein Dahl Karlsen, Lars Ingolf Eide
Saudi Arabia:	Ali Al-Meshari, Hamoud Al-Otaibi
South Africa:	Tony Surridge (Vice Chair), Milingoni Robert Phupheli
United Kingdom:	Philip Sharman
United States:	Mark Ackiewicz, George Guthrie

Representatives of Allied Organizations

IEA GHG:	Tim Dixon

CSLF Secretariat

John Panek, Richard Lynch, Steve Geiger

Invited Speakers

Julio Friedmann, Deputy Assistant Secretary for Clean Coal, United States Department of Energy
Kerry Bowers, President and CEO, Southern Generation Technologies, United States
Neeraj Gupta, Senior Research Leader , Battelle Institute, United States
Jerry Hill, Senior Technical Advisor, Southern States Energy Board, United States
Ramón Treviño, Project Manager, Bureau of Economic Geology, University of Texas, United States

Observers

Canada:	Sean McFadden, Jeff Walker, Tim Wiwchar
Chinese Taipei:	Shih Nan Chen, Linda L.H. Chen, Shoung Ouyang, Ren-Chain Wang
France:	Fabio Dinale
Germany:	Peer Hoth
Japan:	Mike Miyagawa
Korea:	Mijeong Han
Norway:	Frank Ellingsen, Bjørn-Erik Haugan
United Kingdom:	Mark Crombie
United States:	Chris Babel, Raj Barua, Jay Braitsch, Steven Carpenter, Martin Considine, Stephen Comello, Jarad Daniels, David Feng, Christopher Garbacz, Joseph Giove, Deborah Harris, Robert Hilton, Llewellyn King, Arthur Lee, Philip Marston, Jeff Price, Katherine Romanak, Kimberly Sams, John Sicilian, Sharon Sjostrom, Judd Swift, James Wood

1. Chairman's Welcome and Opening Remarks


Trygve Riis

The Chairman of the Technical Group, Trygve Riis, called the meeting to order and welcomed the delegates and observers to Washington.

Mr. Riis provided context for the meeting by mentioning that the Technical Group has completed its work on the 2013 CSLF Technology Roadmap (TRM), which is being launched at this meeting. Four task forces have also been very active since the 2011 CSLF Ministerial Meeting in Beijing, and each has produced a report for this meeting. Three of these task forces have completed their activities, and their final reports have been published and are available at the CSLF website. However, several actions in the Technical Group's Action Plan remain inactive, and one of the items on the meeting agenda is to find ways to move forward on these actions.

2. Introduction of Delegates

Technical Group delegates present for the meeting introduced themselves. Fifteen of the twenty-three CSLF Members were present at this meeting, including representatives from Australia, Canada, China, the European Commission, France, Italy, Japan, Korea, Mexico, the Netherlands, Norway, Saudi Arabia, South Africa, the United Kingdom, and the United States. Observers representing Canada, Chinese Taipei, France, Germany, Japan, Korea, Norway, the United Kingdom, and the United States were also present.

3. Adoption of Agenda

The Agenda was adopted with the understanding that that the order of several items might be changed due to schedule conflicts of some of the meeting participants.

4. Approval of Minutes from Rome Meeting

Jostein Dahl Karlsen requested a small adjustment in Item 12 of the Technical Group minutes from the April 2013 meeting in Rome, Italy, which specified that key messages from the 2013 CSLF TRM would be captured into a document for the Ministerial Meeting. Mr. Karlsen was requested to provide a suggested new wording to the Secretariat, and the Rome minutes were approved as final with the understanding that the Secretariat would make this change.

5. Review of Action Items from Rome Meeting

John Panek provided a brief summary of the seven action items resulting from the Rome meeting. All have been completed or are in progress. For one of the action items, Tony Surridge stated that a study, conducted by the South African Center for Carbon Capture & Storage (SACCCS), on the impacts of CCS on South African national priorities beyond climate change had been completed but was still undergoing evaluation. Dr. Surridge will alert the Secretariat when a final version is available, and the Secretariat will pass this information on to the Technical Group.

6. Report from CSLF Secretariat

John Panek

John Panek gave a presentation that briefly reported on the outcomes of the April 2013 Technical Group meeting in Rome, including the two projects that were recommended by the Technical Group for CSLF recognition. Three other projects are up for recognition at the current meeting. A CO_2 Monitoring Interactive Workshop was held as part of the Rome meeting; presentations and conclusions from the workshop are now online at the CSLF website (there is a link at the “Meetings / Workshops” page).

Mr. Panek noted that the 2013 CSLF Technology Roadmap (TRM) had been completed by the TRM Committee and congratulated the TRM editor, Lars Ingolf Eide, for his work on what is an outstanding document. Mr. Panek also pointed out the existence of two web-based booklets that had been prepared by the Secretariat for this Ministerial Meeting. Information and photos from several of the CSLF-recognized projects have been incorporated into an “Updates from CSLF Recognized Projects” book, and five briefing papers from the Technical Group have been incorporated into the Ministerial Conference Briefing Documents book. Both of these can be downloaded from the Washington pre-meeting page of the CSLF website.

7. Update from the IEA Greenhouse Gas R&D Programme

Tim Dixon gave a presentation about the IEA GHG and its ongoing collaboration with the CSLF’s Technical Group. The two organizations have mutual representation (without voting rights) at Technical Group and IEA GHG Executive Committee meetings, and the IEA GHG has liaison with the CSLF’s Projects Interaction and Review Team in a two-way process for discussing potential activities and projects.

Based on an agreement made back in 2008, the Technical Group is offered the opportunity to propose studies to be undertaken by the IEA GHG. These, along with other proposals from IEA GHG Executive Committee (ExCo) members, go through a selection process at semiannual ExCo meetings. So far there have been three IEA GHG studies that originated from the CSLF Technical Group: "Development of Storage Coefficients for CO_2 Storage in Deep Saline Formations" (March 2010), "Geological Storage of CO_2 in Basalts" (September 2011), and "Potential Implications of Gas Production from Shales and Coal for CO_2 Geological Storage" (November 2013). The next deadline for proposal outlines is in January 2014.

Tim Dixon

Concerning the study on "Potential Implications of Gas Production from Shales and Coal for CO_2 Geological Storage", Mr. Dixon stated that the aim of the study was to assess the potential for geological storage for CO_2 in shale and coal formations and the impact of gas production on CO_2 storage capacity from storage sites whose caprock might have been compromised due to hydraulic fracturing ("fracking"). A key conclusion from the study was that while the fracking process for releasing hydrocarbons from shale and coal seams can potentially decrease storage security, this can be avoided with appropriate reservoir selection and management. The overall estimated CO_2 storage capacity in shale is approximately 740 gigatonnes with a somewhat lesser amount for coal seams. The study uncovered some knowledge gaps that need to be addressed, and in general research is less advanced for CO_2 storage in shales than for coal seams.

8. Report on Activities of the United Kingdom's CCS Cost Reduction Task Force

Activity had been deferred on the "Energy Penalty Reduction" action of the Technical Group Action Plan pending review of the final report from the United Kingdom's Cost Reduction Task Force. This task force was established in March 2012 by the United Kingdom's Department of Energy and Climate Change (DECC) to advise government and industry on the potential for reducing the costs of CCS, so that CCS power projects are financeable and competitive with other low-carbon technologies in the early 2020s.

Philip Sharman

Philip Sharman gave a presentation that summarized the conclusions from this report. The main finding was that United Kingdom gas and coal power stations equipped with CCS have clear potential to be cost competitive with other forms of low-carbon power generation, delivering electricity at a levelized cost approaching £100 per megawatt-hour (MWh) by the early 2020s, and at a cost significantly below £100 per MWh soon thereafter. A short summary of this report has been incorporated into the Ministerial Briefing Documents Book. (*Note: the book is available at the Washington meeting page of the CSLF website.*)

Ensuing discussion revisited the option for forming a Technical Group task force on "Energy Penalty Reduction". Mr. Sharman stated that this report represents a good starting point, but since it represented mainly United Kingdom perspectives a wider initiative would be needed to more inclusively investigate this area. Further action on this item was deferred until later in the meeting when the Technical Group discussed the need for new task forces.

9. CCS in the USA

Julio Friedmann

Julio Friedmann, Deputy Assistant Secretary for Clean Coal in the United States Department of Energy's Office of Fossil Energy, gave a presentation that described the status of CCS policy, research, development, and demonstration activities in the United States. Dr. Friedmann began by stating that this has been a good decade for R&D advancements. New designs are benefitting from larger economies of scale, process enhancements, and process integration, and these have all helped to reduce the cost of CO_2 capture, which has decreased from about $150 per tonne (in 2005) to about $60 per tonne. A near term goal is to further reduce this cost to about $40 per tonne by the year 2020.

Dr. Friedmann stated that the United States Climate Action Plan focuses on power sector CO_2 emissions. This includes about 20 directives and initiatives that collectively aim to reduce United States greenhouse gas emissions, with the most noteworthy element being the development of CO_2 performance standards for stationary power plants. The plan is for these to be promulgated by about the middle of 2016. Looking forward, it may be possible for the United States to reduce its carbon emissions by more than 80% by the year 2050, and to do this CCS would be required for both coal and natural gas power plants.

Dr. Friedmann provided information about the U.S. Department of Energy's Clean Coal Program. The four major areas are: advanced combustion; advanced energy systems; advanced CO_2 capture and compression; and CO_2 storage. The overall goal is to increase net efficiency for power production to greater than 45%, reduce capital costs by 50%, and achieve a $40 per ton CO_2 capture cost with near-zero emissions of airborne pollutants and greenhouse gases and with near-zero net water usage. First generation CCS technologies are now being demonstrated, and pilot-scale tests are starting to occur for second-generation technologies. Currently there are eight major CCS demonstration projects in various stages of development in the United States, including one in operation and two under construction.

Dr. Friedmann stated that eight large-scale tests of CO_2 injection and storage are also ongoing or in the planning stages as part of the Regional Carbon Sequestration Partnerships Program. Seven of these tests will inject between 1-3 million tons of CO_2 over the duration of the test periods. All of these tests will have extensive measurement, monitoring and verification of storage (MMV) components, and information collected will be used as inputs into a series of CCS Best Practices Manuals. Dr. Friedmann concluded his presentation by offering that the future for CCS looks bright, and that there are important new opportunities that need to be pursued. CCS is entering the commercial realm and there will be in some interesting and exciting times ahead.

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

Clinton Foster

The PIRT Chair, Clinton Foster, gave a short presentation that summarized the previous day's PIRT meeting. Outcomes from the meeting were:

- Three projects were approved by the PIRT for Technical Group action: the Kemper County Energy Facility (nominated by the United States and Canada), the Southeast Regional Carbon Sequestration Partnership (SECARB) Phase III Anthropogenic Test and Plant Barry CCS Project (nominated by the United States, Japan, and Canada), and the Midwest Regional Carbon Sequestration Partnership (MRCSP) Development Phase Project (nominated by the United States and Canada).
- The PIRT Terms of Reference and the CSLF Project Submission Form were both updated.
- The PIRT will obtain further information from the Global Carbon Capture and Storage Institute (GCCSI) about its proposal for a co-branded CSLF-GCCSI Knowledge Hub website.

11. Approval of Projects Nominated for CSLF Recognition

Kerry Bowers

Kemper County Energy Facility (*nominated by the United States and Canada*)

Kerry Bowers, President and CEO of Southern Generation Technologies, gave a presentation about the Kemper project. This commercial-scale CCS project, located in east-central Mississippi in the United States, will capture approximately 3 million tonnes of CO_2 per year from an integrated gasification combined cycle (IGCC) power plant, and will include pipeline transportation of approximately 60 miles to an oil field where the CO_2 will be sold for enhanced oil recovery (EOR). The commercial objectives of the project are large-scale demonstration of a next-generation gasifier technology for power production and utilization of a plentiful nearby lignite coal reserve. Approximately 65% of the CO_2 produced by the plant will be captured and utilized.

Construction of the project, including the pipeline, is complete and commercial operation will begin in 2014.

After brief discussion, there was consensus by the Technical Group to recommend to the Policy Group that the Kemper County Energy Facility receive CSLF recognition.

Southeast Regional Carbon Sequestration Partnership (SECARB) Phase III Anthropogenic Test and Plant Barry CCS Project (*nominated by the United States, Japan, and Canada*)

Jerry Hill

Jerry Hill, Senior Technical Advisor at the Southern States Energy Board, gave a presentation about the SECARB project. This large-scale fully-integrated CCS project, located in southeastern Alabama in the United States, brings together components of CO_2 capture, transport, and geologic storage, including monitoring, verification, and accounting of the stored CO_2. A flue gas slipstream from a power plant equivalent to approximately 25 megawatts of power production is being diverted to allow large-scale demonstration of a new amine-based process that can capture approximately 550 tonnes of CO_2 per day. A new 19 kilometer pipeline has also been constructed, as part of the project, for transporting the CO_2 to a deep saline storage site. Objectives of the project are to gain knowledge and experience in operation of a fully integrated CCS large-scale process, to conduct reservoir modeling and test CO_2 storage mechanisms for the types of geologic storage formations that exist along the Gulf Coast of the United States, and to test experimental CO_2 monitoring technologies.

After brief discussion, there was consensus by the Technical Group to recommend to the Policy Group that the SECARB Phase III Anthropogenic Test and Plant Barry CCS Project receive CSLF recognition.

Midwest Regional Carbon Sequestration Partnership (MRCSP) Development Phase Project (*nominated by the United States and Canada*)

Neeraj Gupta

Neeraj Gupta, Senior Research Leader at Battelle, gave a presentation about the MRCSP project. This is a large-scale CO_2 storage project, located in Michigan and nearby states in the northern United States that will, over its four-year duration, inject a total of one million tonnes of CO_2 into different types of oil and gas fields in various lifecycle stages. The project will include collection of fluid chemistry data to better understand geochemical interactions, development of conceptual geologic models for this type of CO_2 storage, and a detailed accounting of the CO_2 injected and recycled. Project objectives are to assess the storage capacity of these oil and gas fields, validate volumetric estimates and numerical models, identify cost-effective monitoring techniques, and develop system-wide information for further understanding of similar geologic formations. Site characterizations are now underway, with long-term CO_2 injection and monitoring to begin in 2015. A final topical report is expected in 2019. Results obtained during this project are expected to provide a foundation for validating that CCS technologies can be commercially deployed in the northern United States.

After brief discussion, there was consensus by the Technical Group to recommend to the Policy Group that the MRCSP Development Phase Project receive CSLF recognition.

12. Update on the 2013 CSLF Technology Roadmap

Trygve Riis, as Chair of the TRM Committee, expanded on his opening remarks concerning the launch of the 2013 CSLF TRM. The TRM was a product of much behind-the-scenes work involving frequent teleconferences between TRM Committee members and ever-evolving versions of the document. Mr. Riis thanked TRM editor Lars Ingolf Eide, the CSLF delegates who provided comments on the drafts of the TRM, and also the Norwegian Ministry of Petroleum and Energy which provided resources in support of the development of the document.

John Panek also offered the CSLF Secretariat's congratulations to TRM editor Eide and mentioned that the 2013 TRM is an online-only document that can be downloaded from the CSLF website. (*Note: the 2013 TRM is available at the Washington meeting page, the "Technology Roadmap" page, and the "Publications" page of the CSLF website*.)

13. Report from Technical Challenges for Conversion of CO_2-EOR to CCS Task Force

Stefan Bachu

The Task Force Chair, Stefan Bachu, gave a brief update on the task force and its final report. The task force's mandate was to review, compile and report on technical challenges that may constitute a barrier to the broad use of CO_2 for enhanced oil recovery (EOR) and to the conversion of CO_2-EOR operations to CCS operations. Economic and policy barriers were outside the scope of the task force. Dr. Bachu stated that the task force's final report contains several key findings:

- There is sufficient operational and regulatory experience for this technology to be considered as being mature, with an associated CO_2 storage rate of the purchased CO_2 greater than 90%.
- The main reason CO_2-EOR is not applied on a large scale outside west Texas in the United States is the unavailability of high-purity CO_2 in the amounts and at the cost needed for this technology to be deployed on a large scale.
- The absence of infrastructure to both capture the CO_2 and transport it from CO_2 sources to oil fields suitable for CO_2-EOR is also a key reason for the lack of large scale deployment of CO_2-EOR.

- There are a number of commonalities between CO_2-EOR and pure CO_2 storage operations, both at the operational and regulatory levels, which create a good basis for transitioning from CO_2-EOR to CO_2 storage in oil fields.
- There are no specific technological barriers or challenges per se in transitioning and converting a pure CO_2-EOR operation into a CO_2 storage operation. The main differences between the two types of operations stem from legal, regulatory and economic differences between the two.
- A challenge for CO_2-EOR operations which may, in the future, convert to CO_2 storage operations is the lack of baseline data for monitoring, and generally monitoring requirements for CCS which are broader and more encompassing than for CO_2-EOR.

Dr. Bachu stated that because there were obvious policy implications in these findings, the CSLF Policy Group should consider establishing a new task force on "Policy, Legal and Regulatory Challenges in the Transitioning from CO_2-EOR to CCS" to examine and address these issues. Dr. Bachu also stated that the Technical Challenges for Conversion of CO_2-EOR to CCS Task Force has accomplished its mandate and is ending its activities, and there was consensus that this task force has concluded its work. (*Note: the task force final report is available at the "Publications" page of the CSLF website.*)

14. Report from CO_2 Utilization Options Task Force

Mark Ackiewicz

The Task Force Chair, Mark Ackiewicz, gave a brief summary of the task force and its Phase 2 final report. The task force was focused on all forms of CO_2 utilization except CO_2-EOR, and its mission was to identify/study the most economically promising CO_2 utilization options that have the potential to yield a meaningful, net reduction of CO_2 emissions, or facilitate the development and/or deployment of other CCS technologies. Mr. Ackiewicz stated that the task force's Phase 2 final report is complete and represents a "snapshot in time" – the status of CO_2 utilization will obviously continue to evolve over time. Options evaluated by the Phase 2 final report included enhanced natural gas recovery (CO_2-EGR), CO_2 for shale gas/oil recovery, urea manufacture, algal fuels, greenhouse utilization, CO_2-assisted geothermal power production, and use of CO_2 in production of aggregate materials for construction. For each option, the task force examined the current state of technology, the current and potential economics, regulatory requirements, technology advancement gaps and research needs, and the potential for co-production. The task force also did an overview survey of any active or planned international projects involving these options.

Mr. Ackiewicz stated that the task force's Phase 2 final report contains several key findings / messages:

- A number of CO_2 utilization options are available which can serve as a mechanism for deployment and commercialization of CCS.

- EOR is the most near-term CO_2 utilization option. Non-EOR CO_2 utilization options are at varying degrees of commercial readiness and technical maturity.
- For mature non-EOR CO_2 utilization options, efforts should be on demonstration projects and on the use of non-traditional feedstocks or polygeneration concepts.
- Efforts that are focused on hydrocarbon recovery other than EOR should focus on field tests.
- Efforts that are in early R&D or pilot-scale stages should focus on addressing key techno-economic challenges, independent tests to verify the performance, and support of small and/or pilot-scale tests of first generation technologies and designs.
- More detailed technical, economic, and environmental analyses should be conducted on these options.

Mr. Ackiewicz stated that the CO_2 Utilization Options Task Force has accomplished its mandate and is ending its activities, and there was consensus that this task force has concluded its work. (*Note: the task force Phase 2 final report is available at the "Publications" page of the CSLF website*.) Sizhen Peng noted that China has completed a new assessment report on CO_2 utilization technology, and agreed to provide a web link for the report.

15. Report from Reviewing Best Practices and Standards for Geologic Storage and Monitoring of CO_2 Task Force


Lars Ingolf Eide

The Task Force Chair, Lars Ingolf Eide, gave a brief update on the task force and its 2013 Annual Report. The task force mandate is to perform initial identification and review of standards for storage and monitoring of injected CO_2. The application of such standards should inform CO_2 crediting mechanisms, but economic and policy/regulatory issues are outside the scope of the task force.

Mr. Eide stated that the ongoing task force work plan includes identification and review of existing standards for geological CO_2 storage and monitoring (on an annual basis); identification of shortcomings and/or weaknesses in standards/guidelines; communication of findings to the ISO/TC 265; producing annual summaries of new as well as updated standards, guidelines and best practice documents regarding geological storage of CO_2 and monitoring of CO_2 sites; and following the work of other organizations related to CO_2 storage.

Mr. Eide stated that the task force's 2013 Annual Report lists more than twenty Best Practices Manuals (BPMs) that now exist (ranging from relatively non-technical to comprehensively technical in scope) with more expected to be published in the coming years. This compilation has shown that site selection, MMV, and risk assessment are well covered by several existing BPMs.

Mr. Eide mentioned that as of 2014 the task force will be moving onto Phase 2 activities, which will have a focus of outlining/designing a web-based solution that can be used for future annual updates. Resources permitting, the task force will also identify the applicability and shortcomings of various BPMs and communicate these results to the

ISO/TC 265 for use in future development of CCS standards in this area. There was consensus that this task force will continue and work toward creating a web-based system (*Note: the task force 2013 Annual Report is available at the "Publications" page of the CSLF website*.)

16. Report from CCS Technology Opportunities and Gaps Task Force

Richard Aldous

The Task Force Chair, Richard Aldous, gave a brief update on the task force and its final report. The task force mandate was to identify and monitor key CCS technology gaps and related issues, to determine the effectiveness of ongoing CCS RD&D for addressing these gaps, and to recommend any RD&D that would address CCS gaps and other issues. The final report covers capture / integrated combustion, CO_2 transport, CO_2 storage, MMV, knowledge / capacity building, and industry dynamics / technology development.

Dr. Aldous stated that there are several key high level observations in the report:

- At a high level there are no major technology gaps. CCS technologies are ready and available, and are being deployed today.
- There are many contending capture technologies, in both current technologies and 2^{nd} & 3^{rd} generation technologies.
- Next generation technologies are vital for substantial cost reduction.
- However, there is no strong market pull for new technologies at the moment.
- There is a need to continue work towards low cost, high resolution MMV, particularly in the offshore environment.
- The lack of exploration for CO_2 storage sites is a significant barrier to rapid deployment of CCS and, thus, learning by doing.

Dr. Aldous stated that it is clearly important that new projects move forward in order to realize projected cost reductions in CCS technologies and it is vital that next generation technologies make it through their development cycles. A key conclusion in the report is that further improvements in CCS technologies will therefore most likely need to be incentivized. Dr. Aldous stated that the CCS Technologies and Gaps Task Force has accomplished its mandate and is ending its activities, and there was consensus that this task force has concluded its work. (*Note: the task force final report is available at the "Publications" page of the CSLF website*.)

17. Report on Technical Group Recommendations and Messages to the Policy Group

Trygve Riis reported that the key messages and recommendations from the task forces have been collected into a room document for the November 6^{th} Policy Group meeting. There is also a similar document for the Policy Group meeting on key messages and recommendations from the 2013 CSLF TRM. Both of these are included in the Documents Book, and Mr. Riis will summarize this information in a presentation at the Policy Group meeting. (*Note: the Documents Book is available at the Washington meeting page of the CSLF website*.)

Mr. Riis also mentioned that separate documents from the Technical Group task forces, as well as a document on key messages and recommendations from the 2013 CSLF TRM, are included in the Ministerial Conference Briefing Documents book. (*Note: the Ministerial Conference Briefing Documents Book is also available at the Washington meeting page of the CSLF website*.)

18. Status of Activities / Discussion of the Need for New Technical Group Task Forces

Trygve Riis thanked the Secretariat for preparing an update on the status of the Technical Group Action Plan. (*Note: the Action Plan Update document is appended to these Minutes*.) Mr. Riis stated that of the twelve actions originally identified, only four have so far resulted in formation of Technical Group task forces, with one other action being assigned to the PIRT and another canceled due to Policy Group activity in that area. However, several other actions are being addressed, at least in part, by other organizations, and there are three actions where there has not yet been any activity.

Mr. Riis suggested that the Technical Group form a review group to appraise all unaddressed items in the Action Plan. This group would review any existing documents and other materials relevant to the unaddressed actions and then recommend (at the next Technical Group meeting) what if any activities are worth pursuing for these actions. After ensuing discussion, there was agreement to create this new working group. Specifics are as follows:

- Action #3: Energy Penalty Reduction. United Kingdom (Philip Sharman) was asked to be lead. Mr. Sharman will discuss this action with the United Kingdom's Department of Energy and Climate Change.
- Action #4: CCS with Industrial Emissions Sources. South Africa (Tony Surridge) was asked to be lead, with support from the United States and the IEA GHG.
- Action #5: CO_2 Compression and Transport. Japan (Ryozo Tanaka) was asked to be lead. Mr. Tanaka will discuss the possibility of leading this action with Japan's Ministry of Economy, Trade and Industry.
- Action #8: Competition of CCS with Other Resources. France (Didier Bonijoly) was asked to be lead.
- Action #9: Lifecycle Assessment and Environmental Footprint of CCS. Norway (Lars Ingolf Eide) was asked to be lead, with support from the United States and the IEA GHG.
- Action #11: Carbon Neutral / Carbon Negative CCS. United Kingdom (Philip Sharman) was asked to be lead. Mr. Sharman will discuss this action with the IEA GHG and the United Kingdom's Department of Energy and Climate Change. The Netherlands (Paul Ramsak) may also participate.

In addition to these existing actions, Stefan Bachu also suggested that the Technical Group add a new item to the Action Plan, for "Review of CO_2 Storage Efficiency in Deep Saline Aquifers". There was consensus to form this new task force and the Secretariat was requested to update the Action Plan. Dr. Bachu volunteered that Canada (himself) would be the task force chair. Other members will be France (Didier Bonijoly), the United States (Angela Goodman and Charles Gorecki, both from the United States Department of Energy's National Energy Technology Laboratory), and Australia (Clinton Foster). The IEA GHG also expressed an interest in this new task force.

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Ramón Treviño

Also, Ramón Treviño of the Bureau of Economic Geology at the University of Texas gave a brief presentation that proposed forming a new task force for investigating sub-seabed CO_2 storage possibilities. The projected scope would include technical issues such as geologic characterization and monitoring, viability of offshore CO_2-EOR, and possible collaboration opportunities with existing projects, and also policy-related issues such as cost, economic drivers, and strategic deployment optimization. One of the goals of the proposed task force would be to support and develop field tests in order to demonstrate global feasibility for offshore sub-seabed CO_2 storage. However, Stefan Bachu stated that supporting and developing a field test was beyond what the CSLF could accomplish due to lack of resources, and suggested that a better mandate for such a task force would be to assess barriers and technical needs for sub-seabed CO_2 storage. There was some support for this revised concept from Norway, South Africa, and the United States, but in the end there were no volunteers to lead a new task force and no consensus to move forward in this area. This may be revisited at the next Technical Group meeting.

19. New Business

The delegation from Korea provided some preliminary information about the next CSLF Technical Group meeting. Chong Kul Ryu stated that the meeting would be held the week of March 24-27, 2014. The first two days of the meeting will be in Seoul and the last two days at a different location. The meeting will include both a technology workshop and a site visit.

20. Review of Consensuses Reached and Action Items

Consensus was reached for the following:

- The Kemper County Energy Facility, the SECARB Phase III Anthropogenic Test and Plant Barry CCS Project, and the MRCSP Development Phase Project are recommended by the Technical Group to the Policy Group for CSLF recognition.
- The Technical Group will further defer addressing the Action Plan on "Energy Penalty Reduction" pending review of the final report by the United Kingdom's Cost Reduction Task Force on this topic.
- The Technical Challenges for Conversion of CO_2-EOR to CCS Task Force has concluded its work.
- The CO_2 Utilization Options Task Force has concluded its work.
- The Technology Opportunities and Gaps Task Force has concluded its work.
- The Task Force on Standards for Geologic Storage and Monitoring of CO_2 will continue and work toward creating a web-based system.
- The Technical Group will create a new working group to appraise all unaddressed items in the Technical Group Action Plan.
- Canada will lead a new task force for "Review of CO_2 Storage Efficiency in Deep Saline Aquifers".

Action items from the meeting are as follows:

Item	Lead	Action
1	Technical Group Chair	Provide the Technical Group's recommendation to the Policy Group that the Kemper County Energy Facility, the SECARB Phase III Anthropogenic Test and Plant Barry CCS Project, and the MRCSP Development Phase Project be recognized by the CSLF. (*Note: this was done at the November 6th Policy Group meeting.*)
2	Norway	Provide suggested text for correction to Rome Technical Group minutes to the CSLF Secretariat for incorporation into final version of minutes. (*Note: correction has been provided.*)
3	South Africa	Alert the Secretariat when the final version is available for the SACCCS report concerning impacts of CCS on South African national priorities beyond climate change.
4	United Kingdom	Send Secretariat the link to the United Kingdom's Needs Assessment Report.
5	Technical Group Chair	Recommend that Policy Group form a new Task Force on "Policy, Legal and Regulatory Challenges in the Transitioning from CO_2-EOR to CCS". (*Note: this was done at the November 6th Policy Group meeting.*)
6	China	Send Secretariat the link to China's assessment report on CO_2 utilization technology. (*Note: link has been provided.*)
7	Canada	Create and lead a new task force for "Review of CO_2 Storage Efficiency in Deep Saline Aquifers". (*Members: Canada, France, United States, and Australia*)
8	Technical Group Action Plan Working Group	Review any existing documents and other materials relevant to the unaddressed Actions Plan items and recommend (at the next Technical Group meeting) what activities are worth pursuing for these actions.
9	CSLF Secretariat	Update the Technical Group Action Plan.

21. Closing Remarks / Adjourn

Trygve Riis thanked the delegates, observers, and Secretariat for their hard work and active participation, and adjourned the meeting.

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Carbon Sequestration Leadership Forum
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CSLF Technical Group Action Plan Update
(as of October 2013)

Action Plan 1: Technology Gaps Closure

Action: The Technical Group will identify and monitor key CCS technology gaps and related issues and recommend any R&D and demonstration activities that address these gaps and issues.

Outcome: Identification of all key technology gaps/issues and determination of the effectiveness of ongoing CCS RD&D for addressing these gaps/issues.

Status: Technology Opportunities and Gaps Task Force (*led by Australia*) active since June 2012. **Final Report issued.**

Action Plan 2: Best-Practice Knowledge Sharing

Action: The Technical Group will facilitate the sharing of knowledge, information, and lessons learned from CSLF-recognized projects and other CCS RD&D.

Outcome: Development of interactive references for assisting next-generation commercial CCS projects, which will include links with other CCS entities.

Status: Activity assigned to Projects Interaction and Review Team (*led by Australia*).

Action Plan 3: Energy Penalty Reduction

Action: The Technical Group will identify technological progress and any new research needs for reducing the energy penalty for CCS, both for traditional CO_2 capture processes and new breakthrough technologies.

Outcome: Identification of opportunities for process improvements and increased efficiency from experiences of "early mover" projects.

Status: United Kingdom (DECC) final report in this area sent to Technical Group delegates on 23 May 2013. **Possible activity in this area to be addressed at Technical Group meeting.**

Action Plan 4: CCS with Industrial Emissions Sources

Action: The Technical Group will document the progress and application of CCS for industrial emissions sources and will identify demonstration opportunities for CSLF Members.

Outcome: Identification of opportunities for CCS with industrial sources. Identification and attempted resolution of technology-related issues (including integration) unique to this type of application.

Status: Clean Energy Ministerial / IEA report issued. **Possible activity in this area to be addressed at Technical Group meeting.**

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Action Plan 5: CO_2 Compression and Transport

Action: The Technical Group will review technologies and assess pipeline standards for CO_2 transport, in particular in relation to impurities in the CO_2 stream. Issues such as thermodynamics, fluid dynamics, and materials of construction, will be considered. Alternatives to pipelines, such as ship transport, will also be assessed.

Outcome: Identification of optimum technical CO_2 transport strategies, both for pipeline and non-pipeline alternatives. Assessment of purity issues as they apply to CO_2 transport. Identification of optimal compression options and alternatives.

Status: No activity yet.

Action Plan 6: Reviewing Best Practices and Standards for Geologic Storage and Monitoring of CO_2

Action: The Technical Group will identify and review standards for CO_2 storage and monitoring.

Outcome: Identification of best practices and standards for storage and monitoring of injected CO_2. The application of such standards should inform CO_2 crediting mechanisms.

Status: Reviewing Best Practices and Standards for Geologic Storage and Monitoring of CO_2 Task Force (*led by Norway*) active since June 2012. Reports for Years 2012 and 2013 issued. **Continuation of Task Force an option.**

Action Plan 7: Technical Challenges for Conversion of CO_2-EOR to CCS

Action: The Technical Group will determine technical and economic aspects that can affect moving from enhanced oil recovery (EOR) to carbon storage.

Outcome: Identification of permitting, monitoring, and reporting requirements for CO_2 EOR applications that apply for CO_2 credits.

Status: Technical Challenges for Conversion of CO_2-EOR to CCS Task Force (*led by Canada*) active since June 2012. **Final Report issued.**

Action Plan 8: Competition of CCS with Other Resources

Action: The Technical Group will examine criteria for assessing competing development priorities between CCS (particularly CO_2 storage) and other economic resources.

Outcome: Identification of criteria for determining relative economic viability of CO_2 storage sites.

Status: **Deferred** pending review of IEA GHG report in this area.

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Action Plan 9: Life Cycle Assessment and Environmental Footprint of CCS

Action: The Technical Group will identify and review methodologies for Life Cycle Assessment (LCA) for CCS, including life cycle inventory analysis, life cycle impact assessment, and interpretation of results.

Outcome: Identification of criteria for determining the full range of environmental effects for CCS technologies.

Status: No activity yet.

Action Plan 10: Risk and Liability

Action: The Technical Group will identify and assess links between technology-related risks and liability.

Outcome: Identification of guidelines for addressing long-term technology-related risks with respect to potential liabilities.

Status: **Canceled.** Policy Group task force formed to investigate this area.

Action Plan 11: Carbon-neutral and Carbon-negative CCS

Action: The Technical Group will investigate technical challenges in use of CCS with power plants that utilize biomass (either pure or co-fired), to determine a pathway toward carbon-neutral or carbon-negative functionality.

Outcomes: Identification of issues and challenges for use of CCS with biomass-fueled power plants.

Status: No activity yet.

Action Plan 12: CO_2 Utilization Options

Action: The Technical Group will investigate CO_2 utilization options.

Outcome: Identification of most economically attractive CO_2 utilization options.

Status: CO_2 Utilization Options Task Force (*led by United States*) active since June 2012. **Final report issued.**

Carbon Sequestration Leadership Forum

www.cslforum.org

CSLF-T-2014-02
24 February 2014

TECHNICAL GROUP

Proposal for New Task Force on Technical Barriers and R&D Opportunities for Offshore, Sub-Seabed Geologic Storage of Carbon Dioxide

Background

The November 2013 CSLF Technical Group Meeting in Washington included a presentation on offshore carbon storage. There was no consensus at that time for a new task force on this topic but subsequently the United States has volunteered to lead such a task force. This paper is a proposal for creating the task force and a brief description of its projected mission and objectives.

Action Requested

The Technical Group is requested to review the proposal for a new task force on Technical Barriers and R&D Opportunities for Offshore, Sub-Seabed Geologic Storage of CO_2.

Carbon Sequestration Leadership Forum
www.cslforum.org
CSLF-T-2014-02
24 February 2014

Proposal for New Task Force on Technical Barriers and R&D Opportunities for Offshore, Sub-Seabed Geologic Storage of Carbon Dioxide

Background:

Offshore geologic storage offers additional carbon dioxide (CO_2) storage opportunities and may have several advantages, such as:

- Avoids issues with heavily populated, onshore areas
- May require only one owner for leasing and pipeline siting
- Reduces difficulty of surface and mineral owner rights, in areas where jurisdiction can be an issue
- Reduces risks to underground drinking water sources
- Provides storage opportunities in areas of many large emission sources along coastlines, and areas that may have potentially limited options for onshore storage

While the number of offshore carbon capture and storage (CCS) projects is limited, one of the most successful CCS projects is an offshore effort that has been demonstrated since 1996 at Statoil's Sleipner field, located approximately 240 kilometers off the coast of Norway in the North Sea. However, the offshore CO_2 geologic storage potential is not well characterized globally as a whole (although some individual countries have performed more in-depth characterization and analysis). There is also a need to understand and address technical challenges associated with the added complexities of operating a CCS project in a marine environment.

At the November 2013 CSLF Ministerial Meeting in Washington, DC, USA, both the Technical and Policy Group meetings included presentations on offshore carbon storage. The Technical Group meeting included a discussion on the topic of offshore storage and the possibility of creating a new task force, however, no consensus was reached at the meeting on the scope of the task force or a volunteer to lead this effort. A similar discussion on offshore storage also occurred during the Policy Group Meeting. Additionally, the Ministerial Communiqué from the meeting noted that offshore geologic storage options are of interest since a diverse suite of options will be necessary for widespread global deployment of CCS.

Proposal:

The United States proposes to serve as chairperson and lead a Technical Group Task Force that is focused on identifying the Technical Barriers and R&D Opportunities for Offshore, Sub-Seabed Geologic Storage of CO_2. The Task Force will develop a report that will:

- Identify existing projects and characterization activities worldwide on offshore CO_2 storage and progress to date;
- Provide a current assessment or understanding (using available analyses) on the status of global offshore storage potential (including potential for offshore enhanced oil recovery (EOR));
- Identify the technical barriers/challenges to offshore CO_2 storage (e.g., characterization, monitoring, transport challenges (a separate task force may be formed for this so would leverage or reference that effort)) and R&D opportunities;
- Identify potential opportunities for global collaboration; and
- Include conclusions and recommendations for consideration by CSLF and its member countries.

Tentative Timeline for Task Force Activities:

Activity	Completion/Due Date
Introduction and Request for Interest in Participation on Task Force	March 27, 2014
Task Force Membership Established	April 30, 2014
Initial/Draft Outline of Report Developed by Task Force	June 30, 2014
Task Force Progress Report to Technical Group	September-December 2014
First Draft of Report Complete	December 31, 2014
Task Force Report Complete/Progress Report to Technical Group	March-May 2015

Carbon Sequestration Leadership Forum
www.cslforum.org

CSLF-T-2014-03
24 February 2014

TECHNICAL GROUP

Action Plan Status Report

Background

At the September 2011 CSLF Ministerial Meeting in Beijing, the Technical Group approved a new multi-year Action Plan to identify priorities and provide a structure and framework for conducting Technical Group efforts through 2016. Twelve individual actions were identified; task forces were formed to address four of these twelve actions, and several other actions were deferred. At the November 2013 Technical Group meeting in Washington, a working group was formed to review any existing documents and other materials relevant to the unaddressed Actions Plan items and recommend which of these unaddressed actions are worth pursuing. Additionally, three of the existing task forces completed their activities and a new action on "Review of CO_2 Storage Efficiency in Deep Saline Aquifers" was approved with a new task force formed.

This paper is an update, prepared by the CSLF Secretariat, on the status of the Technical Group's Action Plan.

Action Requested

The Technical Group is requested to review the Action Plan status report.

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CSLF-T-2014-03
24 February 2014

CSLF Technical Group Action Plan Status

(as of February 2014)

COMPLETED ACTIONS

Technology Gaps Closure

Action: The Technical Group will identify and monitor key CCS technology gaps and related issues and recommend any R&D and demonstration activities that address these gaps and issues.

Outcome: Identification of all key technology gaps/issues and determination of the effectiveness of ongoing CCS RD&D for addressing these gaps/issues.

Status: Final Report has been issued. Key findings are:

- At a high level there are no major technology gaps. CCS technologies are ready and available, and are being deployed today.
- There are many contending capture technologies, in both current technologies and 2nd & 3rd generation technologies.
- Next generation technologies are vital for substantial cost reduction.
- However, there is no strong market pull for new technologies at the moment.
- There is a need to continue work towards low cost, high resolution MMV, particularly in the offshore environment.
- The lack of exploration for CO_2 storage sites is a significant barrier to rapid deployment of CCS and, thus, learning by doing.

Technical Challenges for Conversion of CO_2-EOR to CCS

Action: The Technical Group will determine technical and economic aspects that can affect moving from enhanced oil recovery (EOR) to carbon storage.

Outcome: Identification of permitting, monitoring, and reporting requirements for CO_2 EOR applications that apply for CO_2 credits.

Status: Final Report has been issued. Task force key findings are:

- There is sufficient operational and regulatory experience for this technology to be considered as being mature, with an associated CO_2 storage rate of the purchased CO_2 greater than 90%.
- The main reason CO_2-EOR is not applied on a large scale outside west Texas in the United States is the unavailability of high-purity CO_2 in the amounts and at the cost needed for this technology to be deployed on a large scale.

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- The absence of infrastructure to both capture the CO_2 and transport it from CO_2 sources to oil fields suitable for CO_2-EOR is also a key reason for the lack of large scale deployment of CO_2-EOR.
- There are a number of commonalities between CO_2-EOR and pure CO_2 storage operations, both at the operational and regulatory levels, which create a good basis for transitioning from CO_2-EOR to CO_2 storage in oil fields.
- There are no specific technological barriers or challenges per se in transitioning and converting a pure CO_2-EOR operation into a CO_2 storage operation. The main differences between the two types of operations stem from legal, regulatory and economic differences between the two.
- A challenge for CO_2-EOR operations which may, in the future, convert to CO_2 storage operations is the lack of baseline data for monitoring, and generally monitoring requirements for CCS which are broader and more encompassing than for CO_2-EOR.

CO_2 Utilization Options

Action: The Technical Group will investigate CO_2 utilization options.

Outcome: Identification of most economically attractive CO_2 utilization options.

Status: Final report has been issued. Task force key findings are:

- A number of CO_2 utilization options are available which can serve as a mechanism for deployment and commercialization of CCS.
- EOR is the most near-term CO_2 utilization option. Non-EOR CO_2 utilization options are at varying degrees of commercial readiness and technical maturity.
- For mature non-EOR CO_2 utilization options, efforts should be on demonstration projects and on the use of non-traditional feedstocks or polygeneration concepts.
- Efforts that are focused on hydrocarbon recovery other than EOR should focus on field tests.
- Efforts that are in early R&D or pilot-scale stages should focus on addressing key techno-economic challenges, independent tests to verify the performance, and support of small and/or pilot-scale tests of first generation technologies and designs.
- More detailed technical, economic, and environmental analyses should be conducted on these options.

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ONGOING ACTIONS

Best-Practice Knowledge Sharing

Action: The Technical Group will facilitate the sharing of knowledge, information, and lessons learned from CSLF-recognized projects and other CCS RD&D.

Outcome: Development of interactive references for assisting next-generation commercial CCS projects, which will include links with other CCS entities.

Status: Activity has been assigned to Projects Interaction and Review Team (*led by Australia*). Also, Technical Group is holding annual technology workshops featuring representatives of CSLF-recognized projects.

Reviewing Best Practices and Standards for Geologic Storage and Monitoring of CO_2

Action: The Technical Group will identify and review standards for CO_2 storage and monitoring.

Outcome: Identification of best practices and standards for storage and monitoring of injected CO_2. The application of such standards should inform CO_2 crediting mechanisms.

Status: Task force (*led by Norway*) has been active since June 2012. Reports for Years 2012 and 2013 have been issued.

As of 2014 the task force will be moving onto Phase 2 activities, which will have a focus of outlining/designing a web-based solution that can be used for future annual updates. Resources permitting, the task force will also identify the applicability and shortcomings of various Best Practice Manuals and communicate these results to the ISO/TC 265 for use in future development of CCS standards in this area.

Review of CO_2 Storage Efficiency in Deep Saline Aquifers

Action: The Technical Group will recommend the proper storage efficiency coefficients to be used when estimating CO_2 storage capacity, based on the scale of the assessment, geological characteristics and other parameters of the storage operation.

Outcome: Identification of guidelines for use of appropriate CO_2 storage efficiency coefficients that can be used by governments and industry in the assessment of CO_2 storage resource and in site selection for CO_2 storage.

Status: The CSLF Task Force for Review and Identification of Standards for CO_2 Storage Capacity Estimation published reports in 2005, 2007, and 2008 before concluding its work. New task force (*led by Canada*) has been active since November 2013 and will build on results from the previous task force and published literature since then.

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PROPOSED ACTIONS

Technical Barriers and R&D Opportunities for Offshore, Sub-Seabed Geologic Storage of CO_2

Action: The Technical Group will provide an assessment of the status of global offshore CO_2 storage potential (including potential for offshore EOR).

Outcome: Identification of technical barriers/challenges and potential opportunities for global collaboration on offshore, sub-seabed geologic storage of CO_2.

Status: Proposed new task force (*to be led by United States*). Background paper has been drafted.

Energy Penalty Reduction

Action: The Technical Group will identify technological progress and any new research needs for reducing the energy penalty for CCS, both for traditional CO_2 capture processes and new breakthrough technologies.

Outcome: Identification of opportunities for process improvements and increased efficiency from experiences of "early mover" projects.

Status: United Kingdom was asked to be lead and to report to the Technical Group on feasibility for activity in this area. Projected new task force would build on results from the United Kingdom's Cost Reduction Task Force.

CCS with Industrial Emissions Sources

Action: The Technical Group will document the progress and application of CCS for industrial emissions sources and will identify demonstration opportunities for CSLF Members.

Outcome: Identification of opportunities for CCS with industrial sources. Identification and attempted resolution of technology-related issues (including integration) unique to this type of application.

Status: South Africa was asked to be lead (with support from the United States and the IEA GHG) and to report to the Technical Group on feasibility for activity in this area. Projected new task force would build on the Clean Energy Ministerial / IEA report that has been issued.

CO_2 Compression and Transport

Action: The Technical Group will review technologies and assess pipeline standards for CO_2 transport, in particular in relation to impurities in the CO_2 stream. Issues such as thermodynamics, fluid dynamics, and materials of construction, will be considered. Alternatives to pipelines, such as ship transport, will also be assessed.

Outcome: Identification of optimum technical CO_2 transport strategies, both for pipeline and non-pipeline alternatives. Assessment of purity issues as they apply to CO_2 transport. Identification of optimal compression options and alternatives.

Status: Japan was asked to be lead and to report to the Technical Group on feasibility for activity in this area.

Competition of CCS with Other Resources

Action: The Technical Group will examine criteria for assessing competing development priorities between CCS (particularly CO_2 storage) and other economic resources.

Outcome: Identification of criteria for determining relative economic viability of CO_2 storage sites.

Status: France was asked to be lead and to report to the Technical Group on feasibility for activity in this area.

Life Cycle Assessment and Environmental Footprint of CCS

Action: The Technical Group will identify and review methodologies for Life Cycle Assessment (LCA) for CCS, including life cycle inventory analysis, life cycle impact assessment, and interpretation of results.

Outcome: Identification of criteria for determining the full range of environmental effects for CCS technologies.

Status: Norway was asked to be lead (with support from the United States and the IEA GHG) and to report to the Technical Group on feasibility for activity in this area.

Carbon-neutral and Carbon-negative CCS

Action: The Technical Group will investigate technical challenges in use of CCS with power plants that utilize biomass (either pure or co-fired), to determine a pathway toward carbon-neutral or carbon-negative functionality.

Outcomes: Identification of issues and challenges for use of CCS with biomass-fueled power plants.

Status: United Kingdom was asked to be lead (with possible support from the Netherlands and the IEA GHG) and to report to the Technical Group on feasibility for activity in this area.

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CSLF-T-2014-04
24 February 2014

TECHNICAL GROUP

Possibilities for Collaboration with CSLF Policy Group

Background

The CSLF Policy Group, at its November 2013 meeting in Washington, initiated development of an Action Plan. A Policy Group Exploratory Committee was formed during that meeting which later held a series of teleconferences (in December and January) that resulted in consensus on five topics that would be a primary focus for near term Policy Group activities. Two of these topics are relevant to the Technical Group.

This paper provides background information that may assist the Technical Group in determining how it can best collaborate with the Policy Group for these and other areas. Included are the following two documents:

- The section of the Policy Group minutes for the Washington meeting that pertain to development of a Policy Group Action Plan; and
- The summary of 2014 Policy Group Topics that resulted from the Exploratory Committee's teleconferences.

Sections of these documents of likely interest to the Technical Group are highlighted in yellow.

Action Requested

The Technical Group is requested to review the two documents and develop opinions on how the Technical Group should engage the Policy Group.

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From the November 2013 CSLF Policy Group Meeting Minutes:

11. Development of Policy Group Action Plan

Christopher Smith led a discussion about the possible future agenda for the CSLF Policy Group. To preface the discussion, Mr. Smith stated that the Policy Group consists of experienced and senior policy people in more than twenty governments, and that any forward action plan should aim at finding ways to more effectively amplify and communicate key messages that increase the CCS knowledge base, advances the financing environment for large-scale CCS, and, in the end, helps get projects built. Ensuing discussion mainly centered around two broad topics: improved communications and increasing the knowledge base.

Concerning communications and public outreach, Paul van Slobbe stated that there is a great amount of public opposition to on-shore CO_2 sequestration, due in part to ineffective outreach. The majority of people do not yet know much about CCS and that CO_2 can be effectively stored in a safe manner, and are therefore against any CO_2 storage projects near populous areas. Peer Hoth added that public perception seems to be that CCS is not needed if more money is instead spent on renewable energy, and that there is a fear that storing CO2 underground would result in contamination of underground resources such as fresh water aquifers. Both Mr. van Slobbe and Dr. Hoth endorsed the idea that a future CSLF meeting should host a public perception roundtable, including both proponents and opponents of CCS, as this would allow better understanding on why the public is so reluctant to accept that CCS is both necessary and safe. Louise Barr agreed that there should be a role for the CSLF in increasing the awareness about CCS. Khalid Abuleif offered that the Policy Group needs to have a good communications strategy, and stated that not enough is being done to promulgate knowledge from the CSLF Technical Group. Mr. Smith agreed, adding that the Policy Group should more effectively get information and recommendations from the Technical Group to decision makers in government. Juho Lipponen suggested that the IEA's Greenhouse Gas R&D Programme (the IEA GHG) has a social research network about CCS and could collaborate in any CSLF activities involving public outreach and communications.

Concerning increasing the overall CCS knowledge base, Julio Friedmann proposed several new initiatives for consideration by the Policy Group. Two of these, establishment of an international CCS test center network and investigation of offshore geologic storage options, have been mentioned in the "Moving Forward" section of the Ministerial Communiqué. In addition, Dr. Friedmann suggested that the Policy Group could sponsor a coordinated international science program, in order to understand not just the broad-based scientific and technical issues concerning large-scale CCS projects but also important operational issues as well. Up to now, any such activities have been done mostly in an ad hoc fashion. Dr. Friedmann also proposed that the Policy Group consider a large-scale joint international CCS project, even given that there would be many issues (e.g., governance and funding) that would first need to be solved. Dr. Friedmann stated that even though it would seem to be a hugely ambitious undertaking, projects of this nature always start with a dialogue like the current one. Ensuing discussion resulted in support for the international science program concept. Tone Skogen offered that this could be taken a step further, to coordinate and collaborate on various policy-related issues. Building on that idea, Ms. Barr stated that the Policy Group could perhaps find common threads among all the existing large-scale projects that might assist new projects' efforts to gain financial closure.

2014 CSLF Policy Group Topics
Recommended by Exploratory Committee

The planned path forward is for topics recommended by the Exploratory Committee to be approved by CSLF Policy Group delegates via e-mail communications in the February timeframe, providing approval for teams to form around each major topic. Assuming two CSLF Policy Group meetings annually, this would allow several months for each team to develop a work plan and suggested deliverables that could then be discussed at the next Policy Group meeting (late spring / early summer, exact time/place TBD). It is envisioned that discussion and approval of each team's work plan would be a primary focus of the next Policy Group meeting. As of the second Exploratory Committee call on 8 January, the following topics have emerged as likely to move forward:

COMMUNICATIONS: The CSLF is well-positioned to communicate with Ministers being the only ministerial body focused solely on CCS. Messages should include timely topics (e.g. induced seismicity), be harmonized and closely coordinated with other organizations such as the IEA and GCCSI, and be more frequent than the Ministerial meetings held every two years. The CSLF should also evaluate the potential to communicate directly with other key audiences such as the UNFCCC. Key messages include the need for a "level playing field" or "policy parity" for CCS, and that CCS will ultimately be needed in non-power sector applications such as the cement and steel industries.

GLOBAL COLLABORATION ON LARGE-SCALE CCS PROJECT(S): The CSLF is well-positioned to facilitate discussions on global collaboration efforts for large scale CCS projects, whether as new greenfield projects or by adding additional functionality and value to existing or planned commercial projects. Such efforts could include both on-shore and off-shore deep saline projects. The CSLF Policy Group should also analyze and disseminate policy-relevant lessons from other large-scale projects.

FINANCING FOR CCS PROJECTS: The Policy Group, building on past work under Bernard Frois, should host a series of workshops and discussions on the business case for CCS, including discussion of what business-to-business connections and government-to-government actions the CSLF should support. Outcomes and recommendations should be captured and disseminated to maximize value.

SUPPORTING DEVELOPMENT OF 2ND AND 3RD GENERATION CCS TECHNOLOGIES: Efforts should be taken to better understand the role of 2nd and 3rd generation technologies for achieving widespread CCS deployment, and policies and approaches identified among individual CSLF member countries that can stimulate 2nd and 3rd generation CCS project proposals to improve the outlook for successful Large Scale Integrated Project deployment in the 2020 to 2030 timeframe. Development of these technologies will benefit from the CCS Pilot Scale Testing Network, which is in the process of being stood up.

TRANSITIONING FROM CO2-EOR TO CCS: The Policy Group should look into policy issues based on the findings of the CSLF Technical Group's Task Force on Technical Challenges for Conversion of CO2-EOR to CCS. This has particular relevance in the US, Chinese and European contexts.

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DRAFT

MEETING SUMMARY

Projects Interaction and Review Team (PIRT) Meeting

Washington, D.C., USA

04 November 2013

Prepared by the CSLF Secretariat

LIST OF ATTENDEES

Chair Clinton Foster (Australia)

CSLF Delegates

Australia:	Richard Aldous
Canada:	Eddy Chui
China:	Jiutian Zhang
European Commission:	Jeroen Schuppers
France:	Didier Bonijoly
Italy:	Giuseppe Girardi
Japan:	Ryozo Tanaka
Korea:	Chong Kul Ryu, Chang Keun Yi
Netherlands:	Paul Ramsak
Norway:	Trygve Riis, Lars Ingolf Eide
Saudi Arabia:	Ali Al-Meshari
South Africa:	Tony Surridge
United Kingdom:	Philip Sharman
United States:	Mark Ackiewicz, George Guthrie

CSLF Secretariat John Panek, Richard Lynch, Steve Geiger

Project Sponsors

Kemper County Energy Facility
Kerry Bowers, The Southern Company, United States

SECARB Phase III Anthropogenic Test and Plant Barry Project
Jerry Hill, Southern States Energy Board, United States

MRCSP Development Phase Project
Neeraj Gupta, Battelle Memorial Institute, United States

Observers

France:	Bernard Frois
Norway:	Bjørn-Erik Haugan, Vegar Stokset
United Kingdom:	Mark Crombie, Luke Warren
United States:	Chris Babel, Arthur Lee, Andy Paterson, Kimberly Sams, Robert Van Voorhees, James Wood
IEA GHG:	Tim Dixon

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1. **Welcome and Summary of Previous PIRT Meeting**

PIRT Chairman Clinton Foster of Australia welcomed participants to the 20th meeting of the PIRT and provided a brief summary of the April 2013 PIRT meeting in Rome, Italy. At that meeting the PIRT reached consensus on the following:

Clinton Foster and John Panek

- Recommended that the Uthmaniyah CO_2-EOR Project and the Alberta Carbon Trunk Line Project be approved by the Technical Group and be presented for CSLF recognition at the next Policy Group meeting.
- Deferred consideration of the UNIS CO_2 Lab Project until the next PIRT meeting.
- Continued the use of the current CSLF Project Submission Form pending agreement on a complete revision to the Form.
- Assumed responsibility for all activities related to the Technical Group Action Plan's "Best Practices Knowledge Sharing" action.
- Deferred consideration of the Knowledge Hub proposal until the next PIRT meeting.

The Technical Group subsequently accepted these recommendations at its meeting in Rome.

2. **Adoption of Meeting Agenda**

The meeting Agenda was adopted with no changes.

3. **Introduction of Meeting Attendees**

PIRT meeting attendees introduced themselves. In all, fourteen CSLF delegations were represented at the meeting.

4. **Approval of Meeting Summary from Perth PIRT Meeting**

The Meeting Summary from the April 2013 PIRT meeting in Rome was approved as final with no changes.

5. **Report from CSLF Secretariat**

John Panek gave a presentation that briefly reported on the outcomes of the April 2013 Technical Group meeting in Rome, including the two projects that were recommended by the Technical Group for CSLF recognition. A CO_2 Monitoring Interactive Workshop was held as part of the Rome meeting; presentations and conclusions from the workshop are now online at the CSLF website (there is a link at the "Meetings / Workshops" page). Mr. Panek also mentioned that updates and photos from several of the CSLF-recognized projects were incorporated into a special booklet that can be downloaded from the Washington meeting page of the CSLF website.

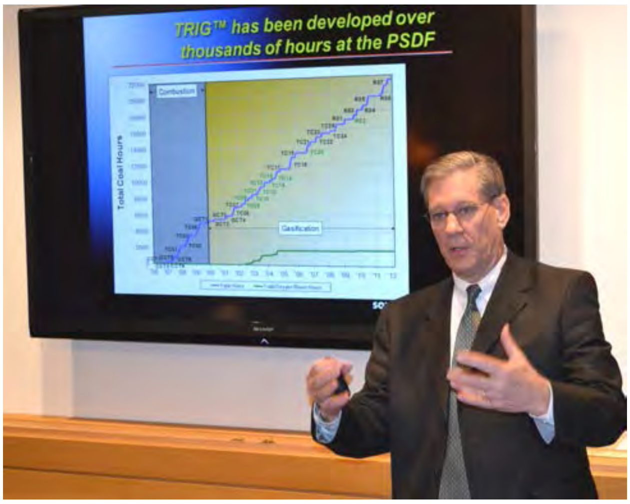
6. Review and Approval of Projects Nominated for CSLF Recognition

The following three projects had been nominated for CSLF recognition:

- Kemper County Energy Facility (nominated by the United States and Canada)
- Southeast Regional Carbon Sequestration Partnership (SECARB) Phase III Anthropogenic Test and Plant Barry Carbon Dioxide (CO2) Capture and Storage (CCS) Project (nominated by the United States, Japan, and Canada)
- Midwest Regional Carbon Sequestration Partnership (MRCSP) Development Phase Project (nominated by the United States and Canada)

Presentations on each of these projects were made by representatives of the project sponsors.

Kemper County Energy Facility



Kerry Bowers

Kerry Bowers, President and CEO of Southern Generation Technologies, gave a presentation about the Kemper project. This commercial-scale CCS project, located in east-central Mississippi in the United States, will capture approximately 3 million tonnes of CO_2 per year from an integrated gasification combined cycle (IGCC) power plant, and will include pipeline transportation of approximately 60 miles to an oil field where the CO_2 will be sold for enhanced oil recovery (EOR). The commercial objectives of the project are large-scale demonstration of a next-generation gasifier technology for power production and utilization of a plentiful nearby lignite coal reserve. Approximately 65% of the CO_2 produced by the plant will be captured and utilized. Construction of the project, including the pipeline, is complete and commercial operation will begin in 2014.

After brief discussion, there was consensus by the PIRT to recommend approval of the Kemper County Energy Facility by the Technical Group.

Southeast Regional Carbon Sequestration Partnership (SECARB) Phase III Anthropogenic Test and Plant Barry CCS Project

Jerry Hill

Jerry Hill, Senior Technical Advisor at the Southern States Energy Board, gave a presentation about the SECARB project. This large-scale fully-integrated CCS project, located in southeastern Alabama in the United States, brings together components of CO_2 capture, transport, and geologic storage, including monitoring, verification, and accounting of the stored CO_2. A flue gas slipstream from a power plant equivalent to approximately 25 megawatts of power production is being diverted to allow large-scale demonstration of a new amine-based process that can capture approximately 550 tons of CO_2 per day. A new 19 kilometer pipeline has also been constructed, as part of the project, for transport of the CO_2 to a deep saline storage site. Objectives of the project are to gain knowledge and experience in operation of a fully integrated CCS large-scale process, to conduct reservoir modeling and test CO_2 storage mechanisms for the types of geologic storage formations that exist along the Gulf Coast of the United States, and to test experimental CO_2 monitoring technologies.

After brief discussion, there was consensus by the PIRT to recommend approval of the SECARB Phase III Anthropogenic Test and Plant Barry CCS Project by the Technical Group.

Midwest Regional Carbon Sequestration Partnership (MRCSP) Development Phase Project

Neeraj Gupta, Senior Research Leader at Battelle, gave a presentation about the MRCSP project. This is a large-scale CO_2 storage project, located in Michigan and nearby states in the northern United States that will, over its four-year duration, inject a total of one million tonnes of CO_2 into different types of oil and gas fields in various lifecycle stages. The project will include collection of fluid chemistry data to better understand geochemical interactions, development of conceptual geologic models for this type of CO_2 storage, and a detailed accounting of the CO_2 injected and recycled. Project objectives are to assess storage capacities of these oil and gas fields, validate static and numerical models, identify cost-effective monitoring techniques, and develop system-wide information for further understanding of similar geologic formations. Site characterizations are now underway, with long-term CO_2 injection and monitoring to begin in 2015. A final topical report is expected in 2019. Results obtained during this project are expected to provide a foundation for validating that CCS technologies can be commercially deployed in the northern United States.

Neeraj Gupta

After brief discussion, there was consensus by the PIRT to recommend approval of the MRCSP Development Phase Project by the Technical Group.

Following review and approval of these three projects, there was brief discussion about the UNIS CO_2 Lab Project, whose approval had been deferred at the April 2013 PIRT meeting in Rome. The project was not approved in Rome because of uncertainty about project funding and also the future of the existing coal-fueled power station in Svalbard, Norway, where the project would be sited. Trygve Riis reported that the future of the power plant is still not clear, and because of this the project has not moved forward. The project sponsor might re-submit the project for consideration at a future PIRT meeting.

7. Review of PIRT Governance

Dr. Foster provided background concerning current PIRT governance issues. The current PIRT Terms of Reference document (ToR) was ratified at the February 2010 PIRT meeting in Canberra, Australia. However, PIRT functions and procedures have evolved considerably since then, and the 2010 ToR has been perceived to be in need of update. There was considerable discussion involving specific edits and additions to the document, and the CSLF Secretariat was asked to prepare a new version that incorporates all the edits. (*Note: the updated ToR is appended to this Meeting Summary*.)

8. Update of CSLF Project Submission Form

Dr. Foster stated that the previous PIRT meeting had made progress on updating the CSLF Project Submission Form, but that the current version of the Project Submission Form would continue to be used pending agreement on a complete revision of the Form. Once again, there was considerable discussion involving specific edits to the document, and in the end there was agreement to eliminate the existing “Project Elements” section, eliminate the “Relevance to CSLF Gaps Analysis” section, and eliminate the three questions under the “Information Availability” section. The CSLF Secretariat was asked to prepare a new version that incorporates all the edits. (*Note: the updated Project Submission Form is appended to this Meeting Summary*.)

9. Discussion of Knowledge-Sharing from CSLF-Recognized Projects

Dr. Foster stated that at the April 2013 Technical Group Meeting in Rome, the PIRT was given the responsibility for the “Best Practices Knowledge Sharing” action of the Technical Group’s Action Plan. However, because the Global Carbon Capture and Storage Institute (GCCSI) is already active in this area, there was agreement that any activities in this area would be deferred until more was known about the CGGSI’s intentions. Dr. Foster noted that the GCCSI has proposed the creation of a new “Knowledge Hub” website that could be “co-branded” with the CSLF and would serve as a gateway to a broad range of information on CCS technologies and projects. This would include connections to other knowledge-sharing sites such as the European CCS Demonstration Project Network. After ensuing discussion, it was decided there was insufficient information as yet to move this forward. For example, Philip Sharman pointed out that the definition of what constitutes a project appears to be different for the CSLF and the GCCSI. Dr. Foster agreed that there would need to be clarification before the PIRT could engage the GCCSI. There was no representative of the GCCSI present, so Dr. Foster stated that he will obtain further information for the PIRT on how the co-branded website would work and on any other GCCSI knowledge-sharing activities that are relevant to the PIRT.

Concerning the CSLF-recognized projects, Mr. Panek stated that the CSLF Secretariat had requested updates from the projects and had developed a booklet for the current meeting from the information received. Projects will be also asked for updates for the next CSLF Annual Meeting, and PIRT delegates may be asked to help facilitate these requests for projects located in their countries.

10. Adjourn

Dr. Foster thanked the attendees for their participation and adjourned the meeting.

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Summary of Consensus Reached

- The PIRT recommends approval by the Technical Group for the Kemper County Energy Facility, the SECARB Phase III Anthropogenic Test and Plant Barry CCS Project, and the MRCSP Development Phase Project.
- The PIRT agrees to an update to the PIRT Terms of Reference and an update to the CSLF Project Submission Form.

Action Items

- The CSLF Secretariat will prepare newly updated versions of the PIRT Terms of Reference and the CSLF Project Submission Form, incorporating edits approved during the PIRT meeting. (*Note: the updated documents are appended below*.)
- The PIRT Chair will obtain further information from the GCCSI about its proposal for a co-branded CSLF-GCCSI Knowledge Hub website and other GCCSI knowledge sharing activities relevant to the PIRT.

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Carbon Sequestration Leadership Forum

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Revised: November 2013

Terms of Reference

CSLF Projects Interaction and Review Team

Background

One of the main instruments to help the CSLF achieve its goals is through the recognition of CSLF projects. Learnings from CSLF projects are key elements to knowledge sharing which will ultimately assist in the acceleration of the deployment of carbon capture and storage (CCS) technologies. It is therefore of major importance to have appropriate mechanisms within the CSLF for the recognition, assessment and dissemination of projects and their results for the benefit of the CSLF and its Members. To meet this need the CSLF has created an advisory body, the PIRT, which reports to the CSLF Technical Group.

PIRT Functions

The PIRT has the following functions:

- Assess projects proposed for recognition by the CSLF in accordance to the project selection criteria developed by the PIRT. Based on this assessment make recommendations to the Technical Group on whether a project should be accepted for recognition by the CSLF.
- Review the CSLF project portfolio and identify synergies, complementarities and gaps, providing feedback to the Technical Group.
- Provide input for further revisions of the CSLF Technology Roadmap (TRM) and respond to the recommended priority actions identified in the TRM.
- Identify where it would be appropriate to have CSLF recognized projects.
- Foster enhanced international collaboration for CSLF projects.
- Ensure a framework for periodically reporting to the Technical Group on the progress within CSLF projects.
- Organize periodic events to facilitate the exchange of experience and views on issues of common interest among CSLF projects and provide feedback to the CSLF.
- Manage technical knowledge sharing activities with other organizations and with CSLF-recognized projects.
- Perform other tasks which may be assigned to it by the CSLF Technical Group.

Membership of the PIRT

The PIRT consists of:

- A core group of Active Members comprising Delegates to the Technical Group, or as nominated by a CSLF Member country. Active Members will be required to participate in the operation of the PIRT.

- An *ad-hoc* group of Stakeholders comprising representatives from CSLF recognized projects. (*note: per Section 3.2 (e) of the CSLF Terms of Reference and Procedures, the Technical Group may designate resource persons*)

The PIRT chair will rotate on an *ad hoc* basis and be approved by the Technical Group.

Projects for CSLF Recognition

- CCS projects seeking CSLF recognition will be considered on their technical merit.
- Projects for consideration must contribute to the overall CSLF goal to "accelerate the research, development, demonstration, and commercial deployment of improved cost-effective technologies for the separation and capture of carbon dioxide for its transport and long-term safe storage or utilization".
  - There is no restriction on project type to be recognized as long as the project meets the criteria listed below.
  - Learnings from similar projects through time will demonstrate progress in CCS.
- Proposals will meet at least one of the following criteria.
  - An integrated CCS project with a capture, storage, and verification component and a transport mechanism for CO_2.
  - Demonstration at pilot- or commercial-scale of new or new applications of technologies in at least one part of the CCUS chain.
  - Demonstration of safe geological storage of CO_2 at pilot- or commercial-scale.

Operation and Procedures of the PIRT

- The PIRT will establish its operational procedures. The PIRT will coordinate with the Technical Group on the agenda and timing of its meetings.
- The PIRT should meet as necessary, often before Technical Group meetings, and use electronic communications wherever possible.
- The TRM will provide guidance for the continuing work program of the PIRT.

Project Recognition

- Project proposals should be circulated to Active Members by the CSLF Secretariat.
- No later than ten days prior to PIRT meetings, Members are asked to submit a free-text comment, either supporting or identifying issues for discussion on each project nominated for CSLF recognition.
- At PIRT meetings or via proxy through the PIRT Chair, individual country representatives will be required to comment on projects nominated for CSLF recognition.
- Recommendations of the PIRT should be reached by consensus with one vote per member country only.

Information Update and Workshops

- Project updates will be requested by the Secretariat annually; the PIRT will assist in ensuring information is sent to the Secretariat.
- The PIRT will facilitate workshops based on technical themes as required.
- As required, the PIRT will draw on external relevant CCS expertise.

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Carbon Sequestration Leadership Forum

Form revision date: November 2013

www.cslforum.org

CSLF PROJECT SUBMISSION FORM

PROJECT TITLE:

PROJECT LOCATION:
Please provide the city (or nearest town), the state/province/region, and the country.

PROJECT GOAL:
Please provide a simple and to-the-point explanation in one or two sentences that can be easily understood by someone with no prior knowledge of the project.

PROJECT OBJECTIVES AND ANTICIPATED OUTCOMES:
Please provide a breakdown of the Project Goal into the constituent steps comprising the whole. Use bullet points to separate the steps and indicate key anticipated outcomes. Indicate what the project does to facilitate CCS deployment.

PROJECT DESCRIPTION AND RELEVANCE (non-technical):
Please provide a concise synopsis of the project (who, what, why, where and how) with easily understandable descriptions of the associated science, technology, and goals. This should include an indication of areas of industrial application and relevance. Target audience: policy makers, press, non-scientific community.

PROJECT DESCRIPTION (technical):
Please provide a more detailed technical description of the project with all significant information. Target audience: engineers and scientists.

PROJECT TIMELINE:
Please provide the project start date, any milestone events (listed chronologically), and the end date. Use most realistic timeline available. Use official (contract signing, etc.) start date. End date should reflect contractual timeline if possible. Use bullet points.

Please also provide answers to the following questions:
Has the project already progressed through the early phases of planning, such as (but not exclusively) documenting the project scope, outputs and outcomes? _______

Has the project management identified the magnitude of resource requirements sufficient to achieve the major milestones of the project? _______

Has the project management identified funding sources for the project? _______

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INFORMATION AVAILABILITY:
Please provide a description of the types of information that will be made available from the project and the outcomes that would be achieved by the project. (Note: It is anticipated that an update on the project will be requested annually by the CSLF. Information provided by the project will be made available at the CSLF website.)

PROJECT CONTACTS:
Please provide name and contact information (including telephone and e-mail) for the project manager or coordinator. If relevant, please also provide name and contact information (including telephone and e-mail) for the person who will handle any requests for site visits.

Please also provide an answer to the following question:
What restrictions, issues, or costs will be assumed by any visitors to the project site?

OTHER PROJECT PARTICIPANTS:
Please provide a listing of all entities who are participating in this project. If available, please also include a management structure diagram or otherwise indicate the role of each participating entity.

PROJECT WEBSITES:
Please provide the web address of the main project website, if one exists. If available, please also provide the web addresses of other project-related websites such as workshops, project presentations, etc.

PROJECT NOMINATORS:
In order to formalize and document the relationship with the CSLF, the project representative and at least two CSLF Members nominating the project must sign the Project Submission Form specifying that relationship before the project can be considered. Alternatively, project representatives and nominators can email the CSLF Secretariat (cslfsecretariat@hq.doe.gov) as an alternative to signatures on the Form..

____
Project Representative
(Affiliation)

____
CSLF Delegate
(CSLF Member)

____
CSLF Delegate
(CSLF Member)

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CSLF Project Elements Checklist

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(Please check all of the following areas that your project will address.)

GENERAL

Project Scale	
Feasibility	
R&D	
Pilot	
Demonstration	
Commercial	

CAPTURE TECHNOLOGIES

Capture Type	
Pre-combustion capture	
Post-combustion capture	
Oxyfuel combustion	
Industrial applications	
Technology	
Advance the capture technology	
Advance plant design for capture efficiency (e.g., boiler, turbine design)	
Improved fuel handling and air separation processes technology	
Improved combustion and flue gas science	
Advance purification and compression technology	
Polygeneration optimization	

TRANSPORT

General	
Tanker Transport	
Pipeline Transport	
Ship transport	
Specifications for impurities from various processes	
Regulations, standards and safety protocols, including response and remediation	

STORAGE AND MONITORING

Storage Complex Type	
Saline formations	
Unconventional reservoirs (e.g basalt, shale)	
Unmineable coal formations	
EOR and/or EGR	
Depleted oil and gas fields	
Storage complex characterization	
CO_2-water-rock (or coal) interactions	
Impact of the quality of CO_2 on storage	
Improved modeling of complex	
Effects of CO_2 rock/water interactions and induced changes in temperature, pressure and stress on permeability, injectivity, migration, trapping and capacity.	
Pressure management (e.g., production of formation water)	
Monitoring the storage complex including risk assessment	
Development of new or improved CO_2 monitoring technologies	
Improve baseline monitoring and distinguish between natural and anthropogenic CO_2	
Development of risk minimization/mitigation methods and strategies, including leakage	
Improve well integrity, well abandonment practices, and/or remediation of existing wells	

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CHARTER FOR THE CARBON SEQUESTRATION LEADERSHIP FORUM: A CARBON CAPTURE AND STORAGE TECHNOLOGY INITIATIVE (REVISED)

The undersigned national governmental entities (collectively the "Members") set forth the following revised Terms of Reference for the Carbon Sequestration Leadership Forum (CSLF), a framework for international cooperation in research, development, demonstration, and commercialization for the separation, capture, transportation, utilization, and storage of carbon dioxide. The CSLF seeks to realize the promise of carbon capture utilization and storage (CCUS) over the coming decades, and to ensure that CCUS is both commercially competitive and environmentally safe.

1. Purpose of the CSLF

To accelerate the research, development, demonstration, and commercial deployment of improved cost-effective technologies for the separation and capture of carbon dioxide for its transport and long-term safe storage or utilization; to make these technologies broadly available internationally; and to identify and address wider issues relating to CCUS. This could include promoting the appropriate technical, political, economic, and regulatory environments for the research, development, demonstration, and commercial deployment of such technology.

2. Function of the CSLF

The CSLF seeks to:

2.1 Identify key obstacles to achieving improved technological capacity;

2.2 Identify potential areas of multilateral collaborations on carbon separation, capture, utilization, transport, and storage technologies;

2.3 Foster collaborative research, development, and demonstration (RD&D) projects reflecting Members' priorities;

2.4 Identify potential issues relating to the treatment of intellectual property;

2.5 Establish guidelines for the collaborations and reporting of their results;

2.6 Assess regularly the progress of collaborative RD&D projects and make recommendations on the direction of such projects;

2.7 Establish and regularly assess an inventory of the potential RD&D needs and gaps;

2.8 Organize collaboration with the international stakeholder community, including industry, academia, financial institutions, government and non-government organizations; the CSLF is also intended to complement ongoing international cooperation;

2.9 Disseminate information and foster knowledge-sharing, in particular among Members' demonstration projects;

2.10 Build the capacity of Members;

2.11 Consult with and consider the views and needs of stakeholders in the activities of the CSLF;

2.12 Initiate and support international efforts to explain the value of CCUS, address issues of public acceptance, legal and market frameworks, and promote broad-based adoption of CCUS;

2.13 Support international efforts to promote RD&D and capacity building projects in developing countries; and

2.14 Conduct such other activities to advance achievement of the CSLF's purpose as the Members may determine.

3. Organization of the CSLF

3.1 A Policy Group and a Technical Group oversee the management of the CSLF. Unless otherwise determined by consensus of the Members, each Member is to make up to two appointments to the Policy Group and up to two appointments to the Technical Group.

3.2 The CSLF operates in a transparent manner. CSLF meetings are open to stakeholders who register for the meeting.

3.3 The Policy Group governs the overall framework and policies of the CSLF, periodically reviews the program of collaborative projects, and provides direction to the Secretariat. The Group should meet at least once a year, at times and places to be determined by its appointed representatives. All decisions of the Group are to be made by consensus of the Members.

3.4 The Technical Group reports to the Policy Group. The Technical Group meets as often as necessary to review the progress of collaborative projects, identify promising directions for research, and make recommendations to the Policy Group on needed actions.

3.5 The CSLF meets at such times and places as determined by the Policy Group. The Technical Group and Task Forces should meet at times that they decide in coordination with the Secretariat.

3.6 The principal coordinator of the CSLF's communications and activities is the CSLF Secretariat. The Secretariat: (1) organizes the meetings of the CSLF and its sub-groups, (2) arranges special activities such as teleconferences and workshops, (3) receives and forwards new membership requests to the Policy Group, (4) coordinates communications with regard to CSLF activities and their status, (5) acts as a clearing house of information for the CSLF, (6) maintains procedures for key functions that are approved by the Policy Group, and (7) performs such other tasks as the Policy Group directs. The focus of the Secretariat is administrative. The Secretariat does not act on matters of substance except as specifically instructed by the Policy Group.

3.7 The Secretariat may, as required, use the services of personnel employed by the Members and made available to the Secretariat. Unless otherwise provided in writing, such personnel are remunerated by their respective employers and remain subject to their employers' conditions of employment.

3.8 The U.S. Department of Energy acts as the CSLF Secretariat unless otherwise decided by consensus of the Members.

3.9 Each Member individually determines the nature of its participation in the CSLF activities.

4. Membership

4.1 This Charter, which is administrative in nature, does not create any legally binding obligations between or among its Members. Each Member should conduct the activities contemplated by this Charter in accordance with the laws under which it operates and the international instruments to which its government is a party.

4.2 The CSLF is open to other national governmental entities and its membership is decided by the Policy Group.

4.3 Technical and other experts from within and without CSLF Member organizations may participate in RD&D projects conducted under the auspices of the CSLF. These projects may be initiated either by the Policy Group or the Technical Group.

5. Funding

Unless otherwise determined by the Members, any costs arising from the activities contemplated by this Charter are to be borne by the Member that incurs them. Each Member's participation in CSLF activities is subject to the availability of funds, personnel, and other resources.

6. Open Research and Intellectual Property

6.1 To the extent practicable, the RD&D fostered by the CSLF should be open and nonproprietary.

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6.2 The protection and allocation of intellectual property, and the treatment of proprietary information, generated in RD&D collaborations under CSLF auspices should be defined by written implementing arrangements between the participants therein.

7. Commencement, Modification, Withdrawal, and Discontinuation

7.1 Commencement and Modification

7.1.1 Activities under this Charter may commence on June 25, 2003. The Members may, by unanimous consent, discontinue activities under this Charter by written arrangement at any time.

7.1.2 This Charter may be modified in writing at any time by unanimous consent of all Members.

7.2 Withdrawal and Discontinuation

A Member may withdraw from membership in the CSLF by giving 90 days advance written notice to the Secretariat.

8. Counterparts

This Charter may be signed in counterpart.

9. Revised Charter

Upon signature of at least five Members, this Charter supersedes and replaces the “Charter of the Carbon Sequestration Leadership Forum (CSLF): A Carbon Capture and Storage Technology Initiative” (June 25, 2003).

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CARBON SEQUESTRATION LEADERSHIP FORUM
TERMS OF REFERENCE AND PROCEDURES

These Terms of Reference and Procedures provide the overall framework to implement the Charter of the Carbon Sequestration Leadership Forum (CSLF). They define the organization of the CSLF and provide the rules under which the CSLF will operate.

1. Organizational Responsibilities

1.1. Policy Group. The Policy Group will govern the overall framework and policies of the CSLF in line with Article 3.2 of the CSLF Charter. The Policy Group is responsible for carrying out the following functions of the CSLF as delineated in Article 2 of the CSLF Charter:

- Identify key legal, regulatory, financial, public perception, institutional-related or other issues associated with the achievement of improved technological capacity.
- Identify potential issues relating to the treatment of intellectual property.
- Establish guidelines for the collaborations and reporting of results.
- Assess regularly the progress of collaborative projects and following reports from the Technical Group make recommendations on the direction of such projects.
- Ensure that CSLF activities complement ongoing international cooperation in this area.
- Consider approaches to address issues associated with the above functions.

In order to implement Article 3.2 of the CSLF Charter, the Policy Group will:

- Review all projects for consistency with the CSLF Charter.
- Consider recommendations of the Technical Group for appropriate action.
- Annually review the overall program of the Policy and Technical Groups and each of their activities.
- Periodically review the Terms of Reference and Procedures.

The Chair of the Policy Group will provide information and guidance to the Technical Group on required tasks and initiatives to be undertaken based upon decisions of the Policy Group. The Chair of the Policy Group will also arrange for appropriate exchange of information between both the Policy Group and the Technical Group.

1.2. Technical Group. The Technical Group will report to the Policy Group and make recommendations to the Policy Group on needed actions in line with Article 3.3 of the CSLF Charter. The Technical Group is responsible for carrying out the following functions of the CSLF as delineated in Article 2 of the CSLF Charter:

- Identify key technical, economic, environmental and other issues related to the achievement of improved technological capacity.

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- Identify potential areas of multilateral collaboration on carbon capture, transport and storage technologies.
- Foster collaborative research, development, and demonstration (RD&D) projects reflecting Members' priorities.
- Assess regularly the progress of collaborative projects and make recommendations to the Policy Group on the direction of such projects.
- Establish and regularly assess an inventory of the potential areas of needed research.
- Facilitate technical collaboration with all sectors of the international research community, academia, industry, government and non-governmental organizations.
- Consider approaches to address issues associated with the above functions.

In order to implement Article 3.2 of the CSLF Charter, the Technical Group will:

- Recommend collaborative projects to the Policy Group.
- Set up and keep procedures to review the progress of collaborative projects.
- Follow the instructions and guidance of the Policy Group on required tasks and initiatives to be undertaken.

1.3. Secretariat. The Secretariat will carry out those activities enumerated in Section 3.5 of the CSLF Charter. The role of the Secretariat is administrative and the Secretariat acts on matters of substance as specifically instructed by the Policy Group. The Secretariat will review all Members material submitted for the CSLF web site and suggest modification where warranted. The Secretariat will also clearly identify the status and ownership of the materials.

2. Additions to Membership

2.1. Application.

Pursuant to Article 4 of the CSLF Charter, national governmental entities may apply for membership to the CSLF by writing to the Secretariat. A letter of application should be signed by the responsible Minister from the applicant country. In their application letter, prospective Members should:

1) demonstrate they are a significant producer or user of fossil fuels that have the potential for carbon capture;
2) describe their existing national vision and/or plan regarding carbon capture and storage (CCS) technologies;
3) describe an existing national commitment to invest resources on research, development and demonstration activities in CCS technologies;
4) describe their commitment to engage the private sector in the development and deployment of CCS technologies; and
5) describe specific projects or activities proposed for being undertaken within the frame of the CSLF.

The Policy Group will address new member applications at the Policy Group Meetings.

2.2. Offer. If the Policy Group approves the application, membership will then be offered to the national governmental entity that submitted the application.

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2.3. Acceptance. The applicant national governmental entity may accept the offer of membership by signing the Charter in Counterpart and delivering such signature to the embassy of the Secretariat. A notarized "true copy" of the signed document is acceptable in lieu of the original. The nominated national governmental entity to which an offer has been extended becomes a Member upon receipt by the Secretariat of the signed Charter.

3. CSLF Governance

3.1. Appointment of Members' Representatives. Members may make appointments and/or replacements to the Policy Group and Technical Group at any time pursuant to Article 3.1 of the CSLF Charter by notifying the Secretariat. The Secretariat will acknowledge such appointment to the Member and keep an up-to-date list of all Policy Group and Technical Group representatives on the CSLF web site.

3.2. Meetings.

(a) The Policy Group should meet at least once each year at a venue and date selected by a decision of the Members.

(b) Ministerial meetings will normally be held approximately every other year. Ministerial meetings will review the overall progress of CSLF collaboration, findings, and accomplishments on major carbon capture and storage issues and provide overall direction on priorities for future work.

(c) The Technical Group will meet as often as necessary and at least once each year at a considered time interval prior to the meeting of the Policy Group.

(d) Meetings of the Policy Group or Technical Group may be called by the respective Chairs of those Groups after consultation with the members.

(e) The Policy and Technical Groups may designate observers and resource persons to attend their respective meetings. CSLF Members may bring other individuals, as indicated in Article 3.1 of the CSLF Charter, to the Policy and Technical Group meetings with prior notice to the Secretariat. The Chair of the Technical Group and whomever else the Technical Group designates may be observers at the Policy Group meeting.

(f) The Secretariat will produce minutes for each of the meetings of the Policy Group and the Technical Group and provide such minutes to all the Members' representatives to the appropriate Group within thirty (30) days of the meeting. Any materials to be considered by Members of the Policy or Technical Groups will be made available to the Secretariat for distribution thirty (30) days prior to meetings.

3.3. Organization of the Policy and Technical Groups

(a) The Policy Group and the Technical Group will each have a Chair and up to three Vice Chairs. The Chairs of the Policy and Technical Groups will be elected every three years.

1) At least 3 months before a CSLF decision is required on the election of a Chair or Vice Chair a note should be sent from the Secretariat to CSLF Members asking for nominations. The note should contain the following:

Nominations should be made by the heads of delegations. Nominations should be sent to the Secretariat. The closing date for nominations should be six weeks prior to the CSLF decision date.

2) Within one week after the closing date for nominations, the Secretariat should post on the CSLF website and email to Policy and Technical Group delegates as appropriate the names of Members nominated and identify the Members that nominated them.
3) As specified by Article 3.2 of the CSLF Charter, the election of Chair and Vice-Chairs will be made by consensus of the Members.
4) When possible, regional balance and emerging economy representation among the Chairs and Vice Chairs should be taken into consideration by Members.

(b) Task Forces of the Policy Group and Technical Group consisting of Members' representatives and/or other individuals may be organized to perform specific tasks as agreed by a decision of the representatives at a meeting of that Group. Meetings of Task Forces of the Policy or Technical Group will be set by those Task Forces.

(c) The Chairs of the Policy Group and the Technical Group will have the option of presiding over the Groups' meetings. Task force leaders will be appointed by a consensus of the Policy and Technical Groups on the basis of recommendations by individual Members. Overall direction of the Secretariat is the responsibility of the Chair of the Policy Group. The Chair of the Technical Group may give such direction to the Secretariat as is relevant to the operations of the Technical Group.

3.4. <u>Decision Making</u>. As specified by Article 3.2 of the CSLF Charter, all decisions will be made by consensus of the Members.

4. CSLF Projects

4.1. <u>Types of Collaborative Projects</u>. Collaborative projects of any type consistent with Article 1 of the CSLF Charter may be recognized by the CSLF as described below. This specifically includes projects that are indicative of the following:

- Information exchange and networking,
- Planning and road-mapping,
- Facilitation of collaboration,
- Research and development,
- Demonstrations, or
- Other issues as indicated in Article 1 of the CSLF Charter.

4.2. <u>Project Recognition</u>. All projects proposed for recognition by the CSLF shall be evaluated via a CSLF Project Submission Form. The CSLF Project Submission Form shall request from project sponsors the type and quantity of information that will allow the project to be adequately evaluated by the CSLF.

A proposal for project recognition can be submitted by any CSLF delegate to the Technical Group and must contain a completed CSLF Project Submission Form. In order to formalize and document the relationship with the CSLF, the representatives of the project sponsors and the delegates of Members nominating a project must sign the CSLF Project Submission Form specifying that relationship before the project can be considered.

The Technical Group shall evaluate all projects proposed for recognition. Projects that meet all evaluation criteria shall be recommended to the Policy Group. A project becomes recognized by the CSLF following approval by the Policy Group.

4.3. Information Availability from Recognized Projects. Non-proprietary information from CSLF-recognized projects, including key project contacts, shall be made available to the CSLF by project sponsors. The Secretariat shall have the responsibility of maintaining this information on the CSLF website.

5. Interaction with Stakeholders

It is recognized that stakeholders, those organizations that are affected by and can affect the goals of the CSLF, form an essential component of CSLF activities. Accordingly, the CSLF will engage stakeholders paying due attention to equitable access, effectiveness and efficiency and will be open, visible, flexible and transparent. In addition, CSLF members will continue to build and communicate with their respective stakeholder networks.

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Terms of Reference

CSLF Projects Interaction and Review Team

Background

One of the main instruments to help the CSLF achieve its goals is through the recognition of CSLF projects. Learnings from CSLF projects are key elements to knowledge sharing which will ultimately assist in the acceleration of the deployment of carbon capture and storage (CCS) technologies. It is therefore of major importance to have appropriate mechanisms within the CSLF for the recognition, assessment and dissemination of projects and their results for the benefit of the CSLF and its Members. To meet this need the CSLF has created an advisory body, the PIRT, which reports to the CSLF Technical Group.

PIRT Functions

The PIRT has the following functions:

- Assess projects proposed for recognition by the CSLF in accordance the project selection criteria developed by the PIRT. Based on this assessment make recommendations to the Technical Group on whether a project should be accepted for recognition by the CSLF.
- Review the CSLF project portfolio and identify synergies, complementarities and gaps, providing feedback to the Technical Group
- Provide input for further revisions of the CSLF Technology Roadmap (TRM) and respond to the recommended priority actions identified in the TRM.
- Identify where it would be appropriate to have CSLF recognized projects.
- Foster enhanced international collaboration for CSLF projects.
- Ensure a framework for periodically reporting to the Technical Group on the progress within CSLF projects.
- Organize periodic events to facilitate the exchange of experience and views on issues of common interest among CSLF projects and provide feedback to the CSLF.
- Manage technical knowledge sharing activities with other organizations and with CSLF-recognized projects.
- Perform other tasks which may be assigned to it by the CSLF Technical Group.

Membership of the PIRT

The PIRT consists of:

- A core group of Active Members comprising Delegates to the Technical Group, or as nominated by a CSLF Member country. Active Members will be required to participate in the operation of the PIRT.

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- An *ad-hoc* group of Stakeholders comprising representatives from CSLF recognized projects. (*note: per Section 3.2 (e) of the CSLF Terms of Reference and Procedures, the Technical Group may designate resource persons*)

The PIRT chair will rotate on an *ad hoc* basis and be approved by the Technical Group.

Projects for CSLF Recognition

- CCS projects seeking CSLF recognition will be considered on their technical merit.
- Projects for consideration must contribute to the overall CSLF goal to "accelerate the research, development, demonstration, and commercial deployment of improved cost-effective technologies for the separation and capture of carbon dioxide for its transport and long-term safe storage or utilization".
  - There is no restriction on project type to be recognized as long as the project meets the criteria listed below.
  - Learnings from similar projects through time will demonstrate progress in CCS.
- Proposals will meet at least one of the following criteria.
  - An integrated CCS project with a capture, storage, and verification component and a transport mechanism for CO_2.
  - Demonstration at pilot- or commercial-scale of new or new applications of technologies in at least one part of the CCUS chain.
  - Demonstration of safe geological storage of CO_2 at pilot- or commercial-scale.

Operation and Procedures of the PIRT

- The PIRT will establish its operational procedures. The PIRT will coordinate with the Technical Group on the agenda and timing of its meetings.
- The PIRT should meet as necessary, often before Technical Group meetings, and use electronic communications wherever possible.
- The TRM will provide guidance for the continuing work program of the PIRT.

Project Recognition

- Project proposals should be circulated to Active Members by the CSLF Secretariat.
- No later than ten days prior to PIRT meetings, Members are asked to submit a free-text comment, either supporting or identifying issues for discussion on each project nominated for CSLF recognition.
- At PIRT meetings or via proxy through the PIRT Chair, individual country representatives will be required to comment on projects nominated for CSLF recognition .
- Recommendations of the PIRT should be reached by consensus with one vote per member country only.

Information Update and Workshops

- Project updates will be requested by the Secretariat annually; the PIRT will assist in ensuring information is sent to the Secretariat.
- The PIRT will facilitate workshops based on technical themes as required.
- As required, the PIRT will draw on external relevant CCS expertise.

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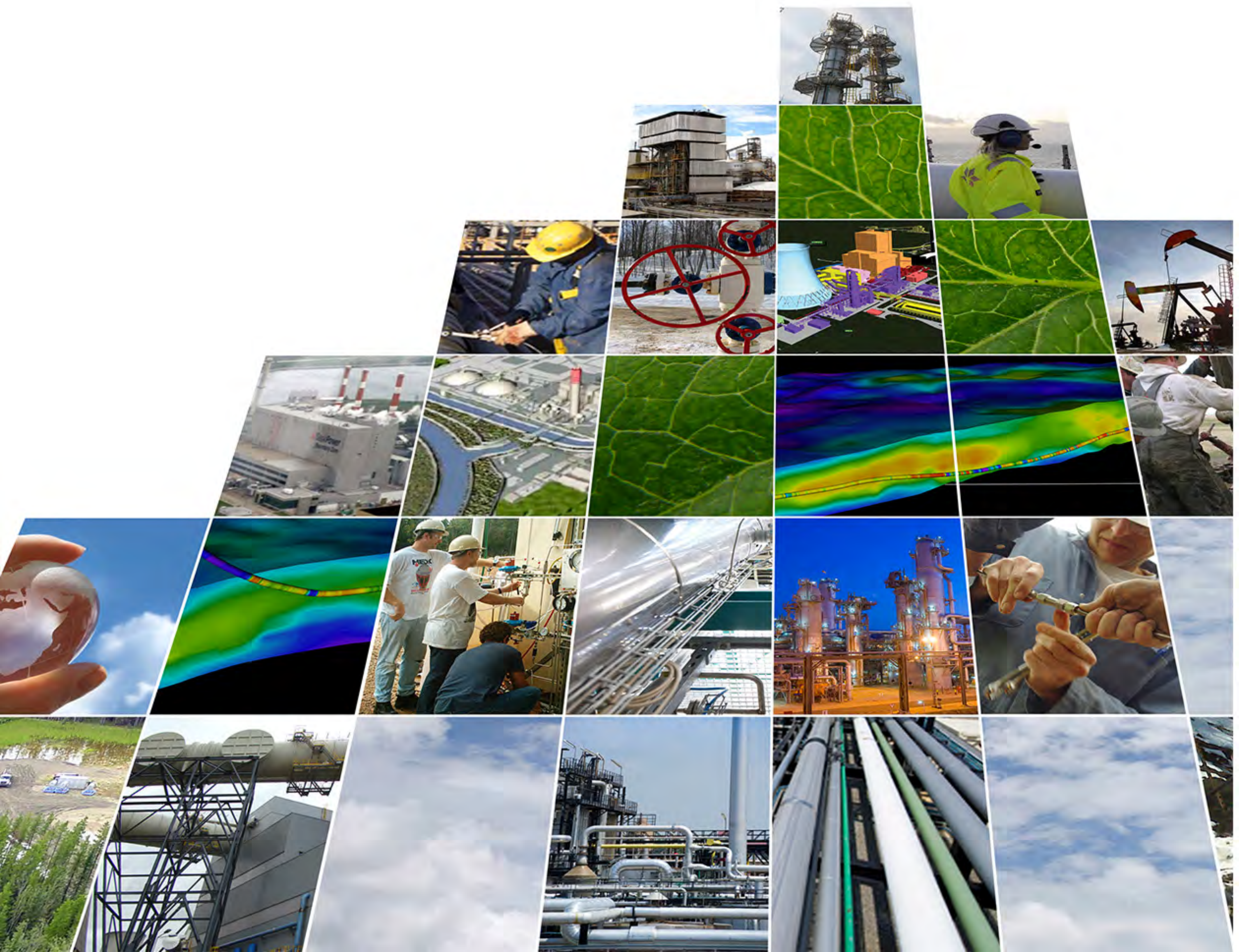
carbon sequestration leadership forum

2013

Carbon Sequestration

TECHNOLOGY ROADMAP



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Carbon Sequestration Leadership Forum
Technology Roadmap 2013

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Executive Summary

The CSLF has issued Technology Roadmaps (TRM) in 2004, 2009, 2010 and 2011. (The TRM 2011 updated only project and country activities, not technology.) This new TRM is in response to a meeting of the CSLF Technical Group (TG) in Bergen in June 2012. It sets out to answer three questions:

- What is the current status of carbon capture and storage (CCS) technology and deployment, particularly in CSLF member countries?
- Where should CCS be by 2020 and beyond?
- What is needed to get from point a) to point b), while also addressing the different circumstances of developed and developing countries?

The focus is on the third question. The TRM covers CCS in the power generation and industrial sectors. Carbon dioxide (CO_2) utilization, particularly in the near-term, is seen as a means of supporting the early deployment of CCS in certain circumstances and accelerating technology deployment.

The TRM is based on a 'status and gap analysis' document for CCS. The essence of the state-of-the-art summary was used to identify priority-action recommendations.

Key conclusions of the TRM are:

- First generation CO_2 capture technology for power generation applications has been demonstrated on a scale of a few tens of MW (in the order of 100,000 tonnes CO_2/year) and two large demonstration plants in the power generation sector (in Canada and the USA) are currently in the 'project execution' phase. Otherwise, CO_2 capture has been successfully applied in the gas processing and fertilizer industries.
- First generation CO_2 capture technology has a high energy penalty and is expensive to implement.
- There is a need to:
    - gain experience from large demonstration projects in power generation;
    - integrate CO_2 capture in power generation so that operational flexibility is retained;
    - identify and implement CO_2 capture for industrial applications, particularly in steel and cement plants; and
    - develop second and third generation CO_2 capture technologies that are designed to reduce costs and the energy penalty whilst maintaining operational flexibility as part of the effort to make CCS commercially viable.
- CO_2 transport is an established technology and pipelines are frequently utilized to transport CO_2 for Enhanced Oil Recovery (i.e., CO_2-EOR). However, further development and understanding is needed to:
    - optimize the design and operation of pipelines and other transport modes (e.g., improved understanding of thermodynamic, corrosion and other effects of impurities in the CO_2 stream; improve and validate dispersion models to address the case of pipeline failure and leakage; and advance the knowledge regarding CO_2 transport by ship); and
    - design and establish CO_2 collection/distribution hubs or clusters, and network transportation infrastructure.
- CO_2 storage is safe provided that proper planning, operating, closure and post-closure procedures are developed and followed. However, as demonstrated by three large-scale and many smaller-scale projects, the sites display a wide variety of geology and other *in situ*

conditions, and data collection for site characterization, qualification[1] and permitting currently requires a long lead-time (3-10 years). Identified research, development and demonstration (RD&D) actions need to:

- intensify demonstration of sizeable storage in a wide range of national and geological settings, onshore as well as offshore;
- further test to validate monitoring technologies in large-scale storage projects and qualify and commercialize these technologies for commercial use;
- develop and validate mitigation and remediation methods for potential leaks and up-scale these to commercial scale;
- further develop the understanding of fundamental processes to advance the simulation tools regarding the effects and fate of the stored CO_2; and
- agree upon and develop consistent methods for evaluating CO_2 storage capacity at various scales and produce geographic maps of national and global distribution of this capacity.

- There are no technical challenges per se in converting CO_2-EOR operations to CCS, although issues like availability of high quality CO_2 at an economic cost, infrastructure for transporting CO_2 to oil fields; and legal, regulatory and long-term liability must be addressed for this to happen.
- There is a broad array of non-EOR CO_2 utilization options that, when taken cumulatively, can provide a mechanism to utilize CO_2 in an economic manner. However, these options are at various levels of technological and market maturity and require:
  - technology development and small-scale tests for less mature technologies;
  - technical, economic, and environmental analyses to better quantify impacts and benefits; and
  - independent tests to verify the performance of any products produced through these other utilization options.
- Public concern and opposition to pipelines for CO_2 transport and geological storage of CO_2 in some countries is a major concern. Further RD&D on storage that includes the elements above and improves aspects of risk management of CO_2 transport and storage sites will contribute to safe long-term storage and public acceptance. The results should be communicated in plain language.

Priority Actions Recommended for Implementation by Policy Makers

Several priority actions for implementation by policy makers are listed in Chapter 5 of this roadmap. It is strongly recommended that governments and key stakeholders implement the actions outlined there. Below is a summary of the key actions that represent activities necessary during the years up to 2020, as well as the following decade. They are challenging but realistic and are spread across all elements of the CCS chain. They require serious dedication and commitment by governments.

Towards 2020 nations should work together to:

- Maintain and increase commitment to CCS as a viable greenhouse gas (GHG) mitigation option
- Establish international networks, test centres and comprehensive RD&D programmes to verify, qualify and facilitate demonstration of CCS technologies

[1] Qualification means that it meets certain internationally agreed criteria and risk management assessment thresholds that give confidence that a new CO_2 storage site is fit for purpose. It does not guarantee permitting approval.

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- Gain experience with 1st generation CO_2 capture technologies and their integration into power plants
- Encourage and support the first industrial demonstration plants for CO_2 capture
- Develop sizeable pilot-scale projects for storage
- Design large-scale, regional CO_2 transport networks and infrastructure
- Agree on common standards, best practices and specifications for all parts of the CCS chain
- Map regional opportunities for CO_2 utilization, addressing the different priorities, technical developments and needs of developed and developing countries.

Towards 2030 nations should work together to:

- Move 2nd generation CO_2 capture technologies for power generation and industrial applications through demonstration and commercialisation, with possible targets of 30% reduction of energy penalty, normalized capital cost, and normalized operational and maintenance (O&M) costs compared to 1st generation technologies
- Implement large-scale national and international CO_2 transport networks and infrastructure
- Demonstrate safe, large-scale CO_2 storage and monitoring
- Qualify regional, and potentially cross-border, clusters of CO_2 storage reservoirs with sufficient capacity
- Ensure sufficient resource capacity for a large-scale CCS industry
- Scale-up and demonstrate non-EOR CO_2 utilization options.

Towards 2050 nations should work together to:

- Develop and progress to commercialisation 3rd generation CO_2 capture technologies with energy penalties and avoidance costs well below that of 1st generation technologies. Possible targets for 3rd generation CO_2 capture technology for power generation and industrial applications are a 50% reduction from 1st generation levels of each of the following: the energy penalty, capital cost, and O&M costs (fixed and non-fuel variable costs) compared to 2013 first generation technologies costs.

Recommendations for Follow-Up Plans

The CSLF will, through its Projects Interaction and Review Team (PIRT), monitor the progress of CCS in relation to the Recommended Priority Actions by soliciting input with respect to the progress of CCS from all members of the CSLF and report annually to the CSLF Technical Group and biennially, or as required, to the CSLF Ministerial Meetings.

1. Objectives, Scope and Approach of TRM

No single approach is sufficient to stabilize the concentration of greenhouse gases (GHGs) in the atmosphere, especially when the growing global demand for energy and the associated potential increase in GHG emissions are considered. Carbon capture and storage (CCS) is one of the important components of any approach or strategy to address the issue of GHG emissions along with improved energy efficiency, energy conservation, the use of renewable energy and nuclear power, and switching from high-carbon fuels to low-carbon fuels.

The CSLF issued Technology Roadmaps (TRM) in 2004, 2009, 2010 and 2011, fulfilling one of its key objectives being to recommend to governments the technology priorities for successful implementation of CCS in the power and industrial sectors. At the meeting of the CSLF Technical Group (TG) in Bergen in June 2012, it was decided to revise the latest version of the TRM.

The TRM sets out to give answers to three questions:

- What is the current status of CCS technology and deployment, particularly in CSLF member countries?
- Where should CCS be by 2020 and beyond?
- What is needed to get from point a) to point b), while also addressing the different circumstances of developed and developing countries?

The focus is on the third question. This TRM will cover CCS in the power generation and industrial sectors. CO_2 utilization, particularly in the near-term, is seen as a means of supporting the early deployment of CCS in certain circumstances and accelerating technology deployment. A CSLF report (CSLF, 2012) divides CO_2 utilization options into three categories:

- Hydrocarbon resource recovery: Applications where CO_2 is used to enhance the production of hydrocarbon resources (such as CO_2-Enhanced Oil Recovery, or CO_2-EOR). This may partly offset the initial cost of CCS and contribute to bridging a gap for the implementation of long-term CO_2 storage in other geological storage media such as deep saline formations.
- Reuse (non-consumptive) applications: Applications where CO_2 is not consumed directly, but re-used or used only once while generating some additional benefit (compared to sequestering the CO_2 stream following its separation). Examples are urea, algal fuel or greenhouse utilization.
- Consumptive applications: These applications involve the formation of minerals, or long-lived compounds from CO_2, which results in carbon sequestration by '*locking-up'* carbon.

For a CO_2-usage technology to qualify as CCS for CO_2 storage in e.g. in trading and credit schemes, it should be required that a n*et amount of* CO_2 is eventually securely and permanently prevented from re-entering the atmosphere. However, emissions can also be reduced without CO_2 being permanently stored, by the substitution of CO_2 produced for a particular purpose with CO_2 captured from a power or industrial plant, as in, e.g., greenhouses in the Netherlands, where natural gas is burned to increase the CO_2.

Economic, financial and policy issues are outside the scope of this CSLF TRM. However, technology improvements will have positive effects both on economic issues and public perception, and in that sense economic and policy issues are implied.

This document was prepared using the following approach:

1. Producing a 'status and gap analysis' document for CCS, including a dedicated CCS technology status report by SINTEF, Norway (2013).
2. Summarizing the CCS status based on the SINTEF report and other available information, including that provided by the Global CCS Institute (GCCSI, 2012) (Chapter 3).

3. Identifying implementation and RD&D needs (Chapter 4).
4. Producing high-level recommendations (Chapter 5).

Towards the completion of this TRM, a report assembled by CO2CRC for the CSLF Task Force on Technical Gaps Closure became available (Anderson et al., 2013). That report, as well as the report by SINTEF (2013), provides more technological details with respect to the technology status and research needs highlighted in this TRM.

The present TRM has endeavoured to consider recent recommendations of other agencies working towards the deployment of commercial CCS, as the issue cuts across organisational and national boundaries and a concerted informed approach is needed.

There has been communication with the International Energy Agency (IEA) during the development of this TRM as the IEA developed a similar document (IEA, 2013). The IEA CCS Roadmap is focused on policy issues and measures, although it includes detailed technology actions in an appendix. In addition, the European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP) has issued recommendations for research in CCS beyond 2020 (ZEP, 2013). The ZEP document only addresses technological aspects of CO_2 capture and it does not address policy issues; its recommendations on CO_2 transport and storage are to be found in the ZEP document (ZEP, 2010)

A Steering Committee comprising members of the CSLF TG and chaired by the TG Chair supervised the work of the TRM editor.

2. Vision and Target - the Importance of CCS

The CSLF Charter, modified at the CSLF Ministerial-level meeting in Beijing in September 2011 to include 'CO_2 utilization', states the following purpose of the organization:

"To accelerate the research, development, demonstration, and commercial deployment of improved cost-effective technologies for the separation and capture of carbon dioxide for its transport and long-term safe storage or utilization; to make these technologies broadly available internationally; and to identify and address wider issues relating to CCS. This could include promoting the appropriate technical, political, economic, and regulatory environments for the research, development, demonstration, and commercial deployment of such technology."

The CSLF has not explicitly stated a vision or specific technology targets. However, according to the IEA Energy Technology Perspectives (ETP) 2012 (IEA, 2012a) the amount of CO_2 captured and stored by 2030 and 2050 will have to be 2.4 and 7.8 $GtCO_2$/year, respectively, to stay within the '2^{o}C scenario' ('2DS'). The cumulative CO_2 reduction from CCS will need to be 123 $GtCO_2$ between 2015 and 2050 and the emissions reductions through the application of CCS by 2050 will have to be split almost equally between power generation and industrial applications. Whereas power generation will have alternatives to CCS for emission reductions, many industries will not. The IEA World Energy Outlook (WEO) 2012 (IEA, 2012b) shows similar contributions from CCS in the 450 ppm scenario up to 2035 and the EU Energy Roadmap 2050 (EU, 2012) points out that CCS will play a significant role to reach 80% reduction of carbon emissions by 2050.

The IEA ETP 2012 (IEA, 2012a) states that, in order to reach 0.27 $GtCO_2$/year captured and stored by 2020, about 120 facilities will be needed. According to views expressed in ETP, *"development and deployment of CCS is seriously off pace"* and "*the scale-up of projects using these technologies over the next decade is critical. CCS could account for up to 20% of cumulative CO_2 reductions in the 2DS* *by 2050. This requires rapid deployment of CCS and this is a significant challenge since there are no large-scale CCS demonstrations in power generation and few in industry".*

The CSLF and its TRM 2013 aspire to play important roles in accelerating the RD&D and commercial deployment of improved, cost-effective technologies for the separation and capture of CO_2, its transport and its long-term safe storage or utilization.

3. Assessment of Present Situation

3.1. Implementation

In January 2013 the Global CCS Institute published its updated report on the Global Status of CCS (GCCSI, 2013). This report identified 72 Large-Scale Integrated CCS Projects (LSIPs)[2], of which eight were categorized as in the 'operation' stage and nine in the 'execution' stage. These 17 projects together would contribute a CO_2 capture capacity of approximately 0.037 $GtCO_2$/year by 2020. Thus the capture *capacity* by 2020 will at best be half of the needed *actual long-term storage* according to the 2DS, even when pure CO_2-EOR projects are included[3]. In this January 2013 update of the 2012 Global Status Report (GCCSI, 2012) the number of projects on the 'execute' list increased by one, whereas the total number of LSIPs went down from 75.

The projects in the 'operation' and 'execution' stages are located in Algeria, Australia, Canada, Norway and the USA. Of the 17 projects in these two categories, six are/will be injecting the CO_2 into deep saline formations, the rest using the CO_2 for EOR operations. So far, the Weyburn-Midale project in Canada is the only CO_2-EOR project that carries out sufficient monitoring to demonstrate permanent storage and has been identified and recognized as a storage project. Two of the 17 projects in the 'operation' and 'execution' stages are in the power generation sector[4]. The other projects capture the CO_2 from sources where the need for additional CO_2 processing before being collected, compressed and transported is limited, such as natural gas processing, synthetic fuel production or fertilizer production. In other industries, projects are in the 'definition' stage (e.g. iron and steel industry in the United Arab Emirates) or the 'evaluation' stage (e.g., cement industry in Norway).

In 2012, there were nine newly identified LSIPs relative to 2011. More than half of these are in China and all will use CO_2 for EOR. Eight LSIPs in the 'definition' or earlier stages were cancelled between 2011 and 2012, due to regulatory issues, public opposition and/or the high investment costs that were not matched by public funding.

3.2. Capture

There are three main routes to capture CO_2: pre-combustion decarbonisation, oxy-combustion and post-combustion CO_2 capture, as presented in Table 1. The table also provides the readiness (High, Medium, Low) of the 1st generation CO_2 capture technologies with reference to power generation

[2] The definition of a LSIP by the Global CCS Institute is that it involves a complete chain of capture, transport and storage of:

- at least 800,000 tonnes per year for coal-based power plants
- at least 400,000 tonnes per year for other plants, including gas-based power plants.

[3] In general, IEA does not count CO_2-EOR projects

[4] The Boundary Dam Integrated Carbon Capture and Sequestration Demonstration Project in Canada that applies post-combustion capture and the Kemper County IGCC in the USA that applies pre-combustion. Both are coal-fired power generation plants.

using solid fuels (predominantly coal) and natural gas, as well as the identified development potential on a rather coarse basis (SINTEF, 2013).

Table 2 summarizes the CO_2 treatment in 1st generation CO_2 capture technologies and the challenges for the 2nd and 3rd generation[5] (SINTEF, 2013). Common challenges – and barriers to implementation – to all capture technologies are the high cost (i.e. capital and operational expenses) and the significant energy penalty associated with the additional equipment. Here we assume 2nd generation technologies will be due for application between 2020 and 2030 and 3rd generation after 2030.

Table 1: Readiness and development potential of main CO_2-capture techniques.

	Readiness for demonstration		Development potential	
Technology	Coal	Natural gas	Coal	Natural gas
IGCC w/CCS*	Medium-High	N/A	High	N/A
Oxy-combustion	Medium-High	Low	High	Medium-High
Post-combustion	High	High	Medium-High	Medium-High

** Integrated Gasification Combined Cycle (IGCC) plant with CCS, i.e. pre-combustion decarbonisation of the power plant.*

There are many demonstration and pilot-scale projects for CO_2 capture technologies, particularly for post-combustion capture and oxy-combustion technologies. The scale of these is generally in the order of 20-30MW_{th}, or a capture capacity of up to a few hundred thousand tonnes of CO_2/year. Dedicated test facilities for the capture of CO_2 have been established in, e.g., Canada, China, Norway, the UK and the USA.

In general, post-combustion CO_2 separation technologies can be used in many industrial applications. ULCOS (Ultra–Low CO_2 Steelmaking) is a consortium of 48 European companies and organizations that launched a cooperative RD&D initiative to enable drastic reductions in CO_2 emissions from steel production. The aim of the ULCOS programme is to reduce CO_2 emissions by at least 50 percent. A demonstration plant in France was planned as part of ULCOS II, but was shelved in late 2012, at least temporarily, as a decision was made to close the steel plant. There has been another project for the steel industry - COURSE50 - in Japan. In this project, two small-scale plants have been operated, one for chemical adsorption and the other for physical adsorption. The European cement industry has carried out a feasibility study on the use of post-combustion capture technology to remove CO_2 from a stack where the various flue gases from the kiln are combined.

[5] Definitions according to the UK Advanced Power Generation Technology Forum (APGTF; 2011):

- 1st generation technologies are technologies that are ready to be demonstrated in 'first-of-a-kind' large-scale projects without the need for further development.
- 2nd generation technologies are systems generally based on 1st generation concepts and equipment with modifications to reduce the energy penalty and CCS costs (e.g. better capture solvents, higher efficiency boilers, better integration) – this may also involve some step-changes to the 'technology blocks'.
- 3rd generation technologies are novel technologies and process options that are distinct from 1st generation technology options and are currently far from commercialisation yet may offer substantial gains when developed.

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Table 2: CO_2 treatment in first generation technologies and the challenges facing second and third generations

	CO_2 treatment 1st generation	Possible 2nd and 3rd generation technology options	Implementation challenges
IGCC with pre-combustion decarbonisat-ion	• Solvents and solid sorbents • Cryogenic air separation unit (ASU)	• Membrane separation of oxygen and syngas • Turbines for hydrogen-rich gas with low NO_x	• Degree of integration of large IGCC plants versus flexibility • Operational availability with coal in base load • Lack of commercial guarantees
Oxy-combustion	• Cryogenic ASU • Cryogenic purification of the CO_2 stream prior to compression • Recycling of flue gas	• New and more efficient air separation, e.g. membranes • Optimized boiler systems • Oxy-combustion turbines • Chemical looping combustion (CLC) - reactor systems and oxygen carriers	• Unit size and capacity combined with energy demand for ASU • Peak temperatures versus flue-gas re-circulation • NO_x formation • Optimisation of overall compressor work (ASU and CO_2 purification unit (CPU) require compression work) • Lack of commercial guarantees
Post-combustion capture	• Separation of CO_2 from flue gas • Chemical absorption or physical absorption (depending on CO_2 concentration)	• New solvents (e.g. amino acids) • 2nd & 3rd generation amines requiring less energy for regeneration • 2nd & 3rd generation process designs and equipment for new and conventional solvents • Solid sorbent technologies • Membrane technologies • Hydrates • Cryogenic technologies	• Scale and integration of complete systems for flue gas cleaning • Slippage of solvent to the surrounding air (possible health, safety & environmental (HS&E) issues) • Carry-over of solvent into the CO_2 stream • Flue gas contaminants • Energy penalty • Water balance (make-up water)

It should be mentioned that the world's largest CO_2 capture plant is a Rectisol process run by Sasol, South Africa, as part of its synfuel/chemical process and captures approximately 25 million tonnes of CO_2 per year.

In short, capturing CO_2 works and there has been significant progress with CO_2 capture from industrial sources with high CO_2 concentration. However, certain challenges remain:

- The cost and energy penalty are high for all 1st generation capture technologies.
- The scale-up and integration of CO_2 capture systems for power generation and industries that do not produce high-purity CO_2 are limited, and may not sufficiently advance for at least the next 5 – 10 years.
- CO_2 capture technologies suited to a range of industrial processes exist, but have not been adopted, demonstrated and validated for specific use. Examples of such industries include cement, iron and steel, petrochemical, aluminium, and pulp and paper.
- Health, safety and environmental assessment must be an integral part of technology and project development. For example, extensive studies have concluded that health and environmental issues connected to amine-based capture technology can be controlled (Maree et al, 2013; Gjernes et al, 2013).

3.3. Transport

Transport of CO_2 in pipelines is a known and established technology, with significant experience gained from more than 6,000 km of CO_2 pipelines onshore in the USA used for transporting CO_2 for EOR operations, mainly across sparsely populated areas. However, there is very limited experience with CO_2 pipelines through heavily populated areas, and the 153km pipeline at Snøhvit is the only offshore CO_2 pipeline. There is also experience of CO_2 transport by ships, albeit in small quantities. These CO_2 streams are almost pure and there is limited experience with CO_2 streams containing impurities.

Standards and best practices on CO_2 transport have emerged (e.g. DNV, 2010). The objectives of further RD&D will be to optimize the design and operation of pipelines and ships and increase the operational reliability in order to reduce costs.

To achieve large-scale implementation, it will also be necessary to think in terms of networks of CO_2 pipelines, ships, railway and road transportation, the latter two particularly in the early stages of a project. Such concepts have been studied at both national and regional levels. Studies have been made around hubs and clusters for CO_2 in the UK, Australia, and in the Dutch ROAD project[6], as well as in the United Arab Emirates and Alberta, Canada (GCCSI, 2012).

In Europe, where CO_2 pipelines will often have to go through heavily populated areas with many landowners, the permitting process and 'right-of-way' negotiations have led to long lead-times for construction. Another factor that may cause long lead-time and expensive pipelines is the increased global demand for steel and pipes.

3.4. Storage

Deep saline formation (DSF) storage projects have been in operation for more than 15 years and CO_2 has been used for EOR since the early 1970s. The three large-scale DSF projects in operation[7], as well as some smaller ones (e.g., in Canada, Germany, Japan and the USA) and a gas reservoir storage project (the Netherlands) have been subjected to extensive monitoring programmes that include a range of technologies, such as time-lapse seismic and down-hole pressure and temperature monitoring, time-lapse gravimetry, controlled-source electromagnetic monitoring, passive seismic monitoring, electrical resistivity imaging, geochemical surveys, inferometric synthetic aperture radar (InSAR) detection, groundwater monitoring, soil-gas detection, microbiological surveys, complex wireline logging and other techniques for plume tracking.

The experience from these and other operations has shown that (GCCSI, 2012):

- CO_2 storage is safe with proper planning and operations. However, presently, there is no experience with closure and post-closure procedures for storage projects (terminated and abandoned CO_2-EOR projects are usually not followed up).
- Current storage projects have developed and demonstrated comprehensive and thorough approaches to site characterization, risk management and monitoring.
- All storage sites are different and need individual and proper characterization. Characterization and permitting requires long lead-times (3-10 years).

Monitoring programmes and the data that they have made available have stimulated the advancement of models that simulate the CO_2 behaviour in the underground environment, including

[6] As of June 2013, the Final Investment Decision (FID) for the ROAD project has not been made but ROAD remains a planned project, close to FID

[7] In Salah, Algeria; Sleipner, Norway; and Snøhvit, Norway

geochemical and geomechanical processes in addition to flow processes. DSF projects in the 'execution' stage have developed extensive monitoring programmes and have been subjected to risk assessments (e.g., the Gorgon Project in Australia and the Quest Project in Canada) and the experience will be expanded when these become operational.

In addition to the impact on CO_2 transport and injection facilities, impurities in the CO_2 stream can have effects on the storage of CO_2 in deep saline formations. Contaminants such as N_2, O_2, CH_4 and Ar will lead to lower storage efficiency (e.g. Mikunda and de Coninck, 2011; IEAGHG, 2011; and Wildgust et al., 2011), but since they have a correspondingly large impact on CO_2 transport costs (compression and pumping), it will be cost-efficient to lower the concentrations to a level where the impact on CO_2 storage efficiency will be minor. Other impurities (e.g. H_2S and SO_2) can occur in concentrations up to a few percent for CO_2 sources relevant for storage. These are generally more reactive chemically (for pipelines, compressors and wells) and geochemically (for storage) than CO_2 itself. So far, there are no indications that the geochemical reactions will have strong impact on injectivity, porosity, permeability or caprock integrity (Mikunda and de Coninck, 2011; IEAGHG, 2011); however, the geochemical part of the site-qualification work needs to take the presence of such impurities into account. Still, geological injection of 'acid gas' (i.e. CO_2 + H_2S) is considered safe (Bachu and Gunter, 2005), and injection of CO_2 with minor concentrations of H_2S should be even more so.

Impurities may also affect the well materials. Most studies have been laboratory experiments on the effects of pure CO_2 streams (Zhang and Bachu, 2011), but well materials may be affected if water returns to the well after injection has stopped (IEAGHG, 2011).

Countries including Australia, Canada and the USA, as well as international bodies like the European Commission (EC) and the OSPAR and London Convention organisations, have implemented legislation and/or regulations concerning CO_2 storage either at the national/federal level or at the provincial/state level[8]. Standards and recommended practices have been published (CSA, 2012; DNV, 2012), in addition to a range of specialized best practice manuals (e.g. on monitoring and verification, DoE 2009 and 2012a; site screening DoE 2010; risk assessment, DoE, 2011 and DNV, 2013; well integrity DNV 2011 and DoE 2012b). The International Organization for Standardization (ISO) has initiated work on a standard covering the whole CCS chain.

Despite this progress, the Global CCS Institute (GCCSI, 2012) stated that most remaining issues regarding regulations for CCS are storage-related, particularly the issue of long-term liability. All these documents will therefore need future revisions based on experience. As an example, the EC CO_2 storage directive is regarded by industrial stakeholders as a regulation that puts too high a liability burden on storage operators. Furthermore, some modifications are still necessary in international regulations such as the London Protocol.

The last few years have seen increased activity in national and regional assessments of storage capacity with the issuing of CO_2 storage 'atlases' in many countries (e.g. Australia, Brazil, Germany, Italy, Japan, North-American countries, the Scandinavian countries, South Africa and the UK). Methods are available for CO_2 storage capacity estimation and comparisons have been made (Bachu, 2007 and 2008; Bachu et al., 2007a and 2007b; DoE, 2008), but there is no generally used common methodology, although in the CO2StoP project, funded by the EC, EU Member States geological surveys and institutes will use a common methodology to calculate their CO_2 storage capacities.

[8] See e.g. http://www.globalccsinstitute.com/networks/cclp

There are additional geological candidates to deep saline formations for CO_2 storage, such as abandoned oil and gas reservoirs and un-minable coal seams, but their capacity is much less than that of deep saline formations. More exotic and unproven alternatives include storing CO_2 in basalts, serpentine-/olivine-rich rocks (but one must find ways to reduce by several orders of magnitude the reaction time between the rock and CO_2 and the energy penalty associated with crushing), as well as in organic-rich shale (but here the effect of hydraulic fracturing of the geological formations has to be better understood).

Experience has shown that the major perceived risks of CCS are associated with CO_2 storage and CO_2 transport. Onshore storage projects have been met with adverse public reaction in Europe although a survey found that just under half (49%) of respondents felt well informed about the causes and consequences of climate change (EC, 2011). However, only 10% of respondents had heard of CCS and knew what it was. A workshop summary (University of Nottingham, NCCCS and University of Sheffield, 2012) provides a detailed overview of the public engagement and perception issues and solutions about CCS projects in Europe as well as their presence in the press.

The risk management of geological storage of CO_2 and early and continued engagement of the local community throughout the lifetime of the CO_2 storage project is therefore essential. Further RD&D on storage should include the elements of risk management of CO_2 storage sites that will help provide the technical foundation to communicate that CO_2 storage is safe. This will include tested, validated and efficient monitoring and leak detection technologies, flow simulations and mitigating options. Equally, plain language communication of technical issues at community level is essential.

3.5. Infrastructure and the Integrated CCS Chain

Coping with the large volumes of CO_2 to be collected from future power plants and industrial clusters, pursuant to, e.g., the 2DS, will require new infrastructure to connect CO_2 sources with CO_2 sinks. In the planning of this infrastructure, the amount of collectible CO_2 – from multiple single CO_2 sources and from CO_2 hubs or clusters – and the availability of storage capacity for the CO_2 must be taken into account to balance the volumes of CO_2 entering the system. This will involve integration of CO_2 capture systems with the power or processing plants, considerations regarding the selection of processes, the integration of different systems, understanding the scale-up risks, solutions for intermediate storage as well as seaborne or land transport ('hub and spokes'), understanding the impact of CO_2 impurities on the whole system, as well as having proper storage sites, which may have a long lead time for selection, characterization and permitting and may be project limiting.

Whilst one can start to gain experience from the integration of CO_2 capture systems into power plants[9], there are presently no CCS clusters and transport networks currently in operation. The closest are EOR systems that inject CO_2 into oil reservoirs as in the Permian basin in the USA, where clusters of oilfields are fed by a network of pipelines. There are initiatives for CO_2 networks, including proposals, in Australia, Canada, Europe (the Netherlands and the UK) and the United Arab Emirates (GCCSI, 2012).

3.6. Utilization

CO_2 for EOR is the most widely used form of CO_2 utilization, with more than 120 operations, mainly in North America. Other specific applications for CO_2-enhanced hydrocarbon recovery include enhanced coal bed methane production (ECBM), enhanced gas recovery (EGR), enhanced gas hydrate recovery (EGHR), hydrocarbon recovery from oil shale and the fracturing of reservoirs to

[9] http://www.cslforum.org/meetings/workshops/technical_london2011.html

increase oil/gas recovery. However, these other applications are processes still being developed or tested in pilot-scale tests (CSLF; 2012, 2013).

Other potential utilization options of CO_2 that will lead to secure long-term storage are the use of CO_2 as the heat-transfer agent in geothermal energy systems, carbonate mineralization, concrete curing, bauxite residue and some algae cultivation. Mixing CO_2 with bauxite residue ('red mud') is being demonstrated in Australia (GCCSI, 2011). In addition, there are several forms of re-use of CO_2 already in use or being explored, including in urea production, utilization in greenhouses, polymers, methanol and formic acid production, and the cultivation of algae as a pathway to bio-energy and other products. These will not lead to permanent storage but may contribute to the reduced production of CO_2 or other CO_2 emitting substances. Also, there may be other related benefits: as an example, the utilization of waste CO_2 in greenhouses in the Netherlands already leads to a better business case for renewable heating and a rapid growth of geothermal energy use in the sector. Finally, the public opinion on CCS as a whole may become more positive when utilization options are part of the portfolio.

For many of the utilization options of CO_2 the total amount that can be permanently stored is, for all practical and economic purposes, limited for the moment. However, in some countries utilization provides early opportunities to catalyse the implementation of CCS. In this way, the CO_2 utilization pathways can form niche markets and solutions as one of the routes to commercial CCS before reaching their own large-scale industrial deployment. This applies not only to oil producing countries but also to regions with evolved energy systems that will allow the implementation of feasible CO_2 business cases.

Recent reviews of utilization of CO_2 are CSLF (2012, 2013), GCCSI (2011), ADEME (2010), Styring (2011), Dijkstra (2012), Tomski (2012) and Markewitz et al. (2012). In April 2013 The Journal of CO2 Utilization was launched, providing a multi-disciplinary platform for the exchange of novel research in the field of CO2 re-use pathways.

4. Identified Technology Needs

4.1. Capture

The main drawbacks of applying first generation CCS technologies to power generation are the increased capital and operational costs that result in higher cost of electricity to the end-user. One cause is the increased fuel demand (typically 30%) due to the efficiency penalty (typically around 10-12%-points in power generation).

Hence, in pursuing 2nd generation technologies, efforts should be made to reduce the energy penalty. This especially applies to:

- CO_2 separation work;
- CO_2 compression work; and,
- to a smaller extent, auxiliary equipment like blower fans and pumps.

The first two components represent the most significant gaps that need improvement in the future.

First generation CO_2 capture technologies have limitations in terms of the energy required for separation work, typically in the range of 3.0–3.5GJ/tCO_2. The theoretical minimum varies with the CO_2 partial pressure, as shown in Figure 1, and is generally below 0.20GJ/tCO_2 for post- and pre-combustion systems. Although this does not include the total energy penalty of a technology, since heat and power are sacrificed in other parts of the process, it indicates that there is a potential for 2nd and 3rd generation capture technologies to reduce the energy penalty by, say, a factor of two.

Note, however, that Figure 1 does not determine which system is best; only a complete analysis of the full systems can tell which case is the better one.

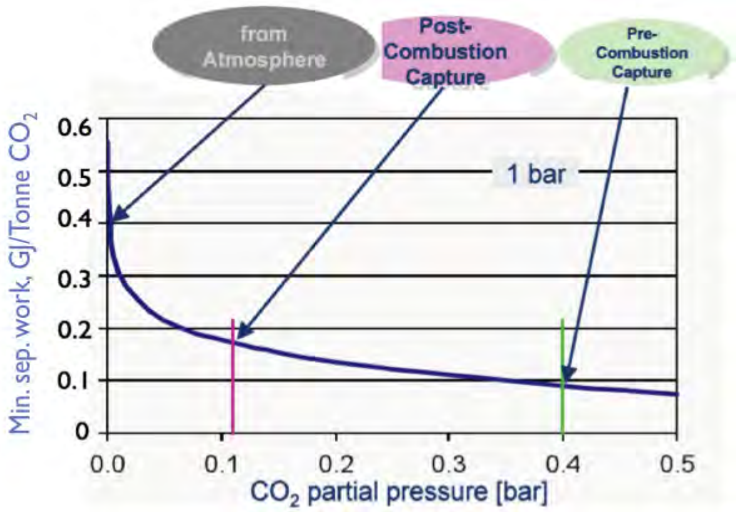

Figure 1: Theoretical minimum separation work of CO_2 from a flue gas depending on the partial pressure of CO_2 [modified from Bolland et al., 2006]

A state-of-the-art, four-stage CO_2 compressor train with inter-cooling requires 0.335GJ/tCO_2 and has a theoretical minimum of about half this value. Hence, it seems that only marginal improvements can be made in compressor development. However, in considering new power generation cycles, process integration is an important aspect. The integration should strive at reducing the overall compression work. In this context, pressurised power cycles should be looked at, especially oxy-combustion cycles and gasification technologies.

History suggests that a successful energy technology requires typically 30 years from the stage it is deemed available to reaching a sufficient market share (typically 1% of the global energy mix). With CCS, in order to have the desired impact on climate change (i.e. the IEA's '2DS'), this transition period must be reduced to just one decade. This requires targeted research with the ambitious goal that 2nd generation CCS technologies will be ready for commercial operations as early as possible between 2020 and 2030, and 3rd generation technologies to be enabled very soon after 2030. Cost reductions will also come from 'learning-by-doing', hence there will be a need for increased installed capacity.

Bio-energy with CO_2 capture and storage ('BECCS') offers permanent net removal of CO_2 from the atmosphere (IEA; 2011, 2013). How 'negative' the emissions may be will depend on several factors, including the sustainability of the biomass used.

The RD&D needs in the CO_2 capture area include:

- Gaining knowledge and experience from 1st generation CO_2 capture technologies.
- Identifying and developing 2nd and 3rd generation CO_2 capture technologies.
- Scaling-up systems for power generation.
- Adapting and scaling-up for industrial applications.
- Integrating a CO_2 capture system with the power or processing plant. Considerations will have to be made regarding process selection, heat integration, other environmental control systems (SO_x, NO_X), part-load operation and daily cycling flexibility, impacts of CO_2 composition and impurities, for 'new-build' plants as well as for retrofits.

- Health, safety and environmental assessment as an integral part of technology and project development, including BECCS; in particular identifying and mitigating/eliminating negative environmental aspects of candidate CO_2 capture technologies.
- Identifying specific cases to demonstrate and validate CO_2 capture technologies suited for a range of industry processes (e.g., cement, iron and steel, petrochemical, and pulp and paper).

4.1.1. Recommendation 1: CO_2 Capture Technologies in Power Generation

Towards 2020: Implement a sufficient number of large-scale capture plants and sizeable pilots to:

- Increase understanding of the scale-up risks. Lessons learned will be used to generate new understanding and concepts complying with 2nd generation CCS.
- Gain experience in the integration of CO_2 capture systems with the power or processing plant, including heat integration and other environmental control systems (SO_x, NO_x).
- Gain experience in part-load operations and daily cycling flexibility, as well as in the impacts of CO_2 composition and impurities.
- Gain experience in the integration of power plants with CCS into electricity grids utilizing renewable energy sources.

Towards 2030:

- Develop 2nd generation CO_2 capture technologies with energy penalties and avoidance costs well below that of 1st generation technologies. Possible targets for 2nd generation capture technology for power generation and industrial applications are a 30% reduction of the each of the following the energy penalty, normalized capital cost, and normalized operational and maintenance (O&M) costs (fixed and non-fuel variable costs) compared to 1st generation technologies[10,11].

Towards 2050:

- Possible targets for 3rd generation CO_2 capture technology for power generation and industrial applications are a 50% reduction of each of the following: the energy penalty, normalized capital cost, and normalized O&M costs (fixed and non-fuel variable costs) compared to 1st generation technologies[12].

4.1.2. Recommendation 2: CO_2 Capture in the Industrial Sector

Towards 2020:

- Further develop CO_2 capture technologies for industrial applications and implement pilot-plants and demonstrations for these.

Towards 2030:

- Implement the full-scale CCS chain in cement, iron and steel and other industrial plants.

The road map for CO_2 capture technology is illustrated in Figure 2.

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[10] Energy penalty = (Power output (state-of-the-art plant w/o CCS) - Power output(state-of-the-art plant w/CCS)) / Energy input (state-of-the-art plant w/o CCS)
Normalized cost = (Cost (state-of-the-art plant w/CCS) – cost (state-of-the-art plant w/o CCS)) / Cost (state-of-the-art plant w/o CCS) E.g. if the energy penalty is 10% in 2013, the penalty should be 7% in 2030.
[11] The target is supported by the UK Carbon Capture and Storage Cost Reduction Task Force of the Department of Energy and Climate Change (DECC, 2013), which states that a reduction of 20% is deemed possible by 2020 and significant further reductions in generation and capture costs are possible by the late 2020s and beyond.
[12] The US Department of Energy/National Energy Technology Laboratory (DOE/NETL, 2011) has a research target of 55% for reduction of the overall economic penalty imparted by current carbon capture technology. DOE/NETL does not attach a date to the target, but state it is aggressive but achievable.

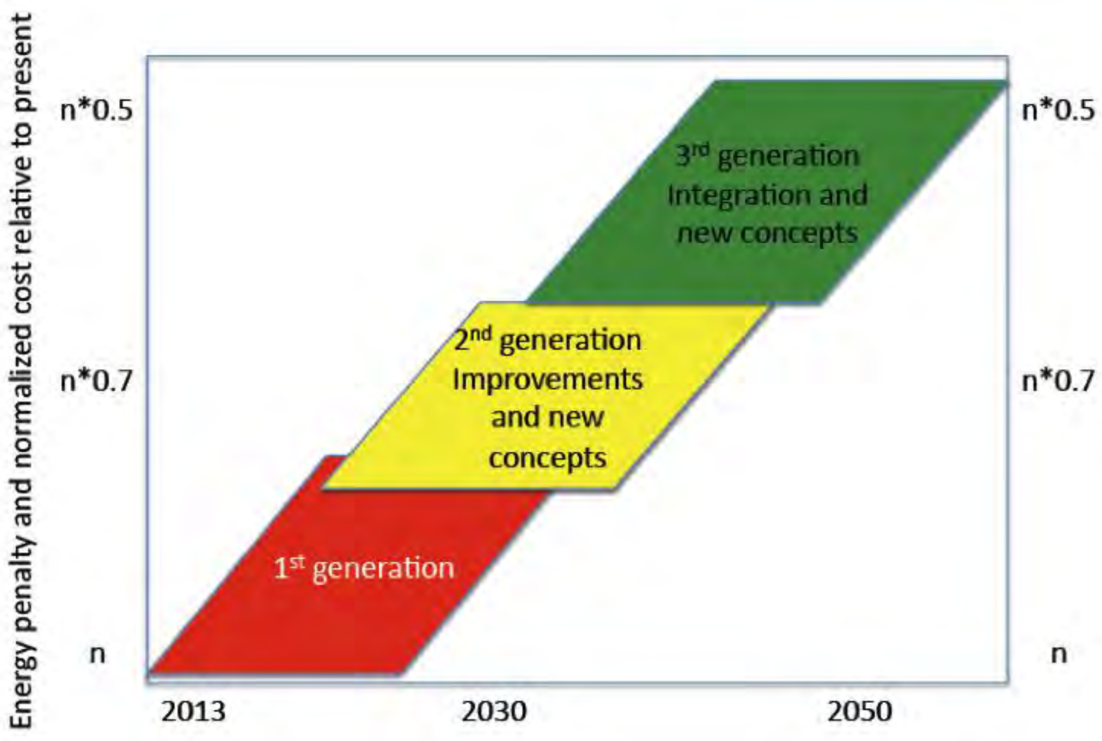

Figure 2: Priorities for CCS technology development. The energy penalty and normalized costs are shown in relation to the present level (n), i.e. equivalent to reduction by 30% in 2030 and 50% towards 2050.

4.2. Transport

RD&D will contribute to optimizing systems for CO_2 transport, thereby increasing operational reliability and reducing costs. The needs include improved understanding and modelling capabilities of properties and the behaviour of CO_2 streams, e.g., the impact of impurities on phase equilibria and equations-of-state of complex CO_2 mixtures, as well as of flow-related phenomena. Other RD&D needs are improved leakage detection and establishment and validation of impact models for the assessment of incidents pursuant to leakage of piped CO_2, the identification and qualification of materials or material combinations that will reduce capital and/or operational costs (including improved understanding of the chemical effect of impurities in the CO_2 stream on pipeline materials, including seals, valves etc.) and the adoption/adaptation of technology elements known from ship transport of other gases to CO_2 transport by ship.

4.2.1. Recommendation 3: CO_2 Transport

Towards 2020:

- Acquire data for, and understand the effects of, impurities on the thermodynamics of CO_2 streams and on pipeline materials, and establish and validate flow models that include such effects.
- Establish and validate dispersion models for the impact assessment of incidents pursuant to leakage of CO_2 from the CO_2 transport system (pipelines, ships, rail and trucks).
- Develop common specifications for pipelines and the CO_2 stream and its components.
- Qualify pipeline materials for use in CO_2 pipes with impurities.

4.3. Storage

Of the three DSF storage projects in operation, two are located offshore and the third one is located in a desert environment. Also the DSF projects currently in the 'execution' stage will be in sparsely populated areas. When attempts have been made to implement CO_2 storage in more heavily populated areas, e.g. in Germany and the Netherlands, they have met considerable public and political opposition that led to project cancellation. A strong reason that the Barendrecht project in the Netherlands did not get approval from the authorities was that CCS is a new technology and is not proven. The public questioned why it should be subjected to the risks of CCS (Spence, 2012; see also Feenstra et al. 2010). The public concerns of risks associated with CCS seem to be mainly around CO_2 storage and this is also where most remaining issues concerning regulations are found, particularly the long-term liability, despite the fact that some countries and sub-national bodies have issued the first versions of CO_2 storage regulations already.

Risk assessment, communication and management are essential activities to ensure qualification of a site for safe, long-term storage of CO_2 by, e.g., a third party and the subsequent approval and permitting by regulatory authorities. However, such qualification does not automatically lead to permission. The risk assessment must include induced seismic activity and ground motion, as well as leakage of CO_2 from the storage unit to the air or groundwater.

Although the effects of impurities in the CO_2 stream on the storage capacity and the integrity of the storage site and wells due to geochemical effects on reservoir and caprock begin to be theoretically understood, there is still need for experimental verification, particularly focussed on site-specific areas. These effects represent risks to storage and need to be better studied and understood.

Geology varies and no two storage sites will be exactly the same, thus CO_2 storage risks are highly site-specific. However, there are many general issues where RD&D is needed to reduce the perceived risks of CO_2 storage and to reduce costs, including risk management.

Elements of risk management where continued and intensified RD&D is needed include:

- Development of methods and protocols for the characterization of the proposed CO_2 storage site that will convince the regulatory agency and the public that storage is secure and safe.
- Development of a unified approach to estimating CO_2 storage capacity.
- Development, validation and commercialization of monitoring methods and tools that are tested and validated for the respective site conditions.
- Improvement of the understanding and modelling of fundamental reservoir and overburden processes, including hydrodynamic, thermal, mechanical and chemical processes.
- Development of good well and reservoir technologies and management procedures.
- Development of tested and verified mitigation measures.
- Identification of where CO_2 storage conflicts with/impacts on other uses and/or resource extraction and inclusion in resource management plans.
- Improvement of understanding and verification of the effects of impurities in the CO_2 stream on all aspects of CO_2 storage.
- Acquisition experience with closure and post-closure procedures for CO_2 storage projects (currently totally lacking).

All these topics require sufficient access to CO_2 storage sites of varying sizes for testing and verification *in situ* and acquisition of data to verify all sorts of models (flow, geomechanical, geochemical etc).

Other issues that need RD&D are:

- Development of a uniform, internationally accepted methodology to estimate CO_2 storage capacity at various scales.
- Proving safe and economic CO_2 storage in alternative geological media such as basalts, serpentine-/olivine-rich rocks and organic-rich shale.

In addition, although not a general RD&D activity but rather a site-specific one, RD&D is needed in:

- Characterizing CO_2 storage sites – this needs to begin as early as possible in any CCS project. There is no shortcut to site characterization.

4.3.1. Recommendation 4: Large-Scale CO_2 Storage

Towards 2020:

- Demonstrate CO_2 storage in a wide range of sizes and geological settings, including deep saline formations, depleted oil and gas fields and producing oil and gas fields (EOR and EGR) around the world.
- Improve the understanding of the effects of impurities in the CO_2 stream, including their phase behaviour, on the capacity and integrity of the CO_2 storage site, with emphasis on well facilities.

Towards 2030:

- Qualify CO_2 storage sites for safe and long-term storage in the scale of tens of millions of tonnes of CO_2 annually per storage site from clusters of CO_2 transport systems.

Towards 2050:

- Have stored over 120 $GtCO_2$ in geological storage sites around the world.

4.3.2. Recommendation 5: Monitoring and Mitigation/Remediation

Towards 2020:

- Further testing, validation and commercialization of monitoring technologies in large-scale CO_2 storage projects, onshore and offshore, to prove that monitoring works and leaks can be prevented or detected, and to make monitoring cost-efficient.
- Develop mitigation and remediation methods for leakage, including well leakage, and test in small-scale, controlled settings.
- Validate mitigation technologies on a large scale, including well leakage.
- Demonstrate safe and long-term CO_2 storage.

Towards 2030:

- Develop a complete set of monitoring and mitigation technologies to commercial availability.

4.3.3 Recommendation 6: Understanding the Storage Reservoirs

Towards 2020:

- Further advance the simulation tools.
- Develop and agree on consistent methods for determining CO_2 storage capacity reserves at various scales (as opposed to storage resources) and global distribution of this capacity (important for policy makers).

4.4. Infrastructure and the Integrated CCS Chain

Building the infrastructure needed to handle large volumes of CO_2 requires that one moves on from the studies and projects mentioned in Section 3.5. Some of the needed technology activities are mentioned above, such as the integration of a CO_2 capture system with the power or processing plant and understanding the scale-up risks.

Other RD&D needs include:

- Designing a CO_2 transport system that involves pipelines, solutions for intermediate CO_2 storage and seaborne or land transport (hub and spokes).
- Developing systems that collect CO_2 from multiple sources and distribute it to multiple sinks.
- Characterizing and selecting qualified CO_2 storage sites, which have a long lead-time and may be project limiting. Several sites must be characterized, as a given site will not be able to receive a constant flow of CO_2 over time and flexibility with respect to site must be secured.
- Safety and environmental risk assessments for the whole chain, including life-cycle analysis (LCA).

In addition to these technology challenges, there are non-technical risks that include the cooperation of different industries across the CCS value-chain, the lack of project-on-project confidence, the completion of projects on cost and on schedule, operational availability and reliability, financing and political aspects. These risks are outside the scope of the CSLF TRM 2013.

4.4.1. Recommendation 7: Infrastructure

Towards 2020:

- Design large-scale CO_2 transport networks that integrate capture, transport and storage, including matching of sources and sinks, particularly in non-OECD countries.
- Map the competing demands for steel and pipes and secure the manufacturing capacity for the required pipe volumes and other transport items.
- Develop systems for metering and monitoring CO_2 from different sources with varying purity and composition that feed into a common collection and distribution system.
- Start the identification, characterization and qualification of CO_2 storage sites for the large-scale systems.

Towards 2030:

- Implement large-scale CO_2 transport networks that integrate CO_2 capture, transport and storage, including matching of sources and sinks, particularly in non-OECD countries.

4.5. Utilization

There are technical and policy reasons to further examine the technical challenges of the utilization of CO_2. The recent reviews of utilization by CSLF (2012, 2013), GCCSI (2011) and Styring (2011) all point to several possible topics requiring RD&D, including:

- Improving the understanding of how to increase and prove the permanent storage of CO_2 in CO_2-EOR operations. A recent CSLF Task Force Report (Bachu et al., 2013) points out the similarities and differences between CO_2-EOR and CO_2 injected for storage. One conclusion from this report is that there are no technical challenges per se in converting CO_2-EOR operations to CCS, although issues like availability of high quality CO_2 at an economic cost, infrastructure for transporting CO_2 to oil fields; and legal, regulatory and long-term liability must be addressed.
- Improving the understanding of how to increase and prove the permanent storage of CO_2 in EGR, ECBM, EGHR, enhanced shale gas recovery and other geological applications of CO_2.
- Developing and applying carbonation approaches (i.e. for the production of secondary construction materials).
- Developing large-scale, algae-based production of fuels.
- Improving and extending the utilization of CO_2 in greenhouses, urea production and other reuse options.

CO_2-EOR has the largest potential of the various CO_2 utilization options described previously, and has not been sufficiently explored to date as a long-term CO_2 storage option. So far only the CO_2-EOR

Weyburn-Midale project in Canada has performed extensive monitoring and verification of CO_2 stored in EOR operations.

4.5.1. Recommendation 8: CO_2 Utilization

Towards 2020:

- Resolve technical challenges for the transition from CO_2-EOR operations to CO_2 storage operations.
- Establish methods and standards that will increase and prove the permanent storage of CO_2 in EGR, ECBM, EGHR and other geological applications if CO_2 injection becomes more prevalent in these applications.
- Research, evaluate and demonstrate carbonation approaches, in particular for mining residue carbonation and concrete curing, but also other carbonate mineralization that may lead to useful products (e.g. secondary construction materials), including environmental barriers such as the consequences of large mining operations and the disposal of carbonates.
- Map opportunities, conduct technology readiness assessments and resolve main barriers for the implementation of the CO_2 utilization family of technologies including life-cycle assessments and CO_2 and energy balances.
- Increase the understanding of CO_2 energy balances for each potential CO_2 re-use pathways and the energy requirement of each technology using technological modelling.
- Address policy and regulatory issues related to CO_2 utilization, particularly in enhanced hydrocarbon recovery.

5. Priority Actions Recommended for Implementation by Policy Makers

Towards 2020 nations should work together to:

- Maintain and increase commitment to CCS as a viable GHG mitigation option, building upon the global progress to date.
- Establish international networks of laboratories (like the European Carbon Dioxide Capture and Storage Laboratory Infrastructure, ECCSEL) and test centres, as well as comprehensive RD&D programmes to:
    - verify and qualify 1st generation CO_2 capture technologies;
    - continue development of 2nd and 3rd generation CO_2 capture technologies; and
    - share knowledge and experience.
- Implement large-scale demonstration projects in power generation in a sufficient number to gain experience with 1st generation CO_2 capture technologies and their integration into the power plant;
- Encourage and support the first demonstration plants for CO_2 capture in other industries than the power sector and gas processing and reforming, particularly in the cement and iron and steel industries.
- Develop common specifications for impurities in the CO_2 stream for the transport and storage of CO_2
- Establish R&D programmes and international collaborations that facilitate the demonstration and qualification of CO_2 storage sites.
- Develop internationally agreed common standards or best practices for establishing CO_2 storage capacity in geological formations.
- Develop sizeable pilot-scale projects for CO_2 storage that can provide greater understanding of the storage medium, establish networks of such projects to share the knowledge and experience for various geological and environmental settings, jurisdictions and regions of the world, including monitoring programmes.

- Develop common standards or best practices for the screening, qualification and selection of CO_2 storage sites in order to reduce lead-time and have the sites ready for permitting between 2020 and 2025, including CO_2-enhanced oil recovery (CO_2-EOR) sites.
- Design large-scale, regional CO_2 transport networks and infrastructure that integrate CO_2 capture from power generation as well as other industries, CO_2 transport and storage, with due consideration to:
    - competition with other resources and access;
    - matching of sources and sinks, particularly in non-OECD countries;
    - competing demands for steel and pipes and securing the necessary manufacturing capacity; and
    - lead-times for qualification and permitting of CO_2 storage sites and planning and approval of pipeline routes.
- Conduct regional (nationally as well as internationally) impact assessments of large-scale CCS implementation as part of an energy mix with renewables and fossil fuels.
- Map regional opportunities for CO_2 utilization and start implementing projects.
- Continue R&D and small-scale testing of promising non-EOR CO_2 utilization options.
- Address the different priorities, technical developments and needs of developed and developing countries.

Towards 2030 nations should work together to:

- Move 2nd generation CO_2 capture technologies for power generation and industrial applications through demonstration and commercialisation. Compared to 1st generation technologies possible targets for 2nd generation capture technology for power generation and industrial applications are a 30% reduction of each of the following: the energy penalty, normalized capital cost, and normalized operational and maintenance (O&M) costs (fixed and non-fuel variable costs) compared to 1st generation technologies.
- Implement large-scale regional CO_2 transport networks and infrastructure, nationally as well as internationally.
- Demonstrate safe, large-scale CO_2 storage and monitoring
- Qualify regional, and potentially cross-border, clusters of CO_2 storage sites with sufficient capacity.
- Ensure sufficient resource capacity for a large-scale CCS industry.
- Scale-up and demonstrate non-EOR CO_2 utilization options.

Towards 2050 nations should work together to:

- Develop and progress to commercialisation 3rd generation CO_2 capture technologies with energy penalties and avoidance costs well below that of 1st generation technologies. Possible targets for 3rd generation capture technology for power generation and industrial applications are a 50% reduction from 1st generation levels of each of the following: the energy penalty, capital cost, and O&M costs (fixed and non-fuel variable costs) compared to first generation technologies.

6. Summary and Follow-Up Plans

Since the last full update of the CSLF TRM in 2010, there have been advances and positive developments in CCS, although at a lower rate than is necessary to achieve earlier objectives. R&D of CO_2 capture technologies progresses, new Large-Scale Integrated Projects (LSIPs) are under construction or have been decided, legislation has been put in place in many OECD-countries and several nations have mapped potential CO_2 storage sites and their capacities. An important next step will be to develop projects that expand the range of CO_2 capture technologies for power and industrial plants to demonstration at a large scale. This will provide much-needed experience at a scale approaching or matching commercial scale and the integration of capture technologies with the rest of the plant, paving the way for subsequent cost reductions. There is also a need to get experience from a wider range of CO_2 transport means, as well as of CO_2 of different qualities. Furthermore, there are only a limited number of large-scale CO_2 storage projects, and experience is needed from a large number of geological settings and monitoring schemes under commercial conditions.

A rapid increase of the demonstration of all the 'links' in the CCS 'chain', in power generation and industrial plants, as well as continued and comprehensive RD&D will be essential to reach, e.g., the '2DS' emission target. The CSLF will need to monitor progress in light of the Priority Actions suggested above, report the findings at the Ministerial meetings and suggest adjustments and updates of the TRM. The CSLF can then be a platform for an international coordinated effort to commercialize CCS technology.

Several bodies monitor the progress of CCS nationally and internationally, the most prominent probably being the Global CCS Institute through its annual Global Status of CCS reports. However, the CSLF will need to have these status reports condensed in order to advise Ministerial meetings in a concise and consistent way. To this end, it is recommended that the CSLF will, through its Projects Interaction and Review Team (PIRT), monitor the progress in CCS in relation to the Recommended Priority Actions.

Through the CSLF Secretariat, the PIRT will:

- solicit input with respect to progress of CCS from all members of the CSLF;
- gather information from a wide range of sources on the global progress of CCS;
- prepare a simple reporting template that relates the progress of the Priority Actions;
- report annually to the CSLF TG; and
- report biennially, or as required, to the CSLF Ministerial Meetings.

The PIRT should be given the responsibility to prepare plans for and be responsible for future updates of the CSLF TRM.

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Abbreviations and Acronyms

2DS	IEA ETP 2012 2°C scenario
ACTL	Alberta Carbon Trunk Line
APGTF	Advanced Power Generation Technology Forum (UK)
ASU	air separation unit
BECCS	bio-energy with carbon capture and storage
CCS	carbon capture and storage
CO_2-EOR	enhanced oil recovery using CO_2
CSLF	Carbon Sequestration Leadership Forum
CSA	Canadian Standards Association
CSU	CO_2 purification unit
DECC	Department of Energy and Climate Change (United Kingdom)
DOE	Department of Energy (USA)
DSF	deep saline formation
EC	European Commission
ECBM	enhanced coal bed methane recovery
ECCSEL	European Carbon Dioxide Capture and Storage Laboratory Infrastructure
EGHR	enhanced gas hydrate recovery
EGR	enhanced gas recovery
EOR	enhanced oil recovery
ETP	Energy Technology Perspectives (of the IEA)
EU	European Union
GCCSI	Global CCS Institute
HS&E	health, safety and environmental
IEA	International Energy Agency
IEAGHG	IEA Greenhouse Gas Research and Development Programme
IGCC	integrated gasification combined cycle
InSAR	inferometric synthetic aperture radar
ISO	International Organization for Standardization
LCA	life-cycle assessment
LSIP	large-scale integrated project
NCCCS	Nottingham Centre for Carbon Capture and Storage
NETL	National Energy Technology Laboratory (USA)
O&M	operation and maintenance
OECD	Organization for Economic Co-operation and Development
OSPAR	Oslo and Paris Conventions
RD&D	research, development and demonstration
ROAD	Rotterdam Opslag en Afvang Demonstratieproject (Rotterdam Capture and Storage Demonstration Project)
TG	Technical Group (of the CSLF)
TRM	Technology Roadmap
WEO	World Energy Outlook (of the IEA)
UK	United Kingdom
ULCOS	Ultra-low CO_2 Steelmaking consortium
USA	United States of America
ZEP	European Technology Platform for Zero Emission Fossil Fuel Power Plants

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Active and Completed CSLF Recognized Projects

(as of December 2013)

1. **Air Products CO_2 Capture from Hydrogen Facility Project**
Nominators: United States (lead), Netherlands, and United Kingdom
This is a large-scale commercial project, located in eastern Texas in the United States, which will demonstrate a state-of-the-art system to concentrate CO_2 from two steam methane reformer (SMR) hydrogen production plants, and purify the CO_2 to make it suitable for sequestration by injection into an oil reservoir as part of an ongoing CO_2 Enhanced Oil Recovery (EOR) project. The commercial goal of the project is to recover and purify approximately 1 million tonnes per year of CO_2 for pipeline transport to Texas oilfields for use in EOR. The technical goal is to capture at least 75% of the CO_2 from a treated industrial gas stream that would otherwise be emitted to the atmosphere. A financial goal is to demonstrate real-world CO_2 capture economics.
Recognized by the CSLF at its Perth meeting, October 2012

2. **Alberta Carbon Trunk Line**
Nominators: Canada (lead) and United States
This large-scale fully-integrated project will collect CO_2 from two industrial sources (a fertilizer plant and an oil sands upgrading facility) in Canada's Province of Alberta industrial heartland and transport it via a 240-kilometer pipeline to depleted hydrocarbon reservoirs in central Alberta for utilization and storage in EOR projects. The pipeline is designed for a capacity of 14.6 million tonnes CO_2 per year although it is being initially licensed at 5.5 million tonnes per year. The pipeline route is expected to stimulate EOR development in Alberta and may eventually lead to a broad CO_2 pipeline network throughout central and southern Alberta.
Recognized by the CSLF at its Washington meeting, November 2013

3. **Alberta Enhanced Coal-Bed Methane Recovery Project** ***(Completed)***
Nominators: Canada (lead), United States, and United Kingdom
This pilot-scale project, located in Alberta, Canada, aimed at demonstrating, from both economic and environmental criteria, the overall feasibility of coal bed methane (CBM) production and simultaneous CO_2 storage in deep unmineable coal seams. Specific objectives of the project were to determine baseline production of CBM from coals; determine the effect of CO_2 injection and storage on CBM production; assess economics; and monitor and trace the path of CO_2 movement by geochemical and geophysical methods. All testing undertaken was successful, with one important conclusion being that flue gas injection appears to enhance methane production to a greater degree possible than with CO_2 while still sequestering CO_2, albeit in smaller quantities.
Recognized by the CSLF at its Melbourne meeting, September 2004

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4. **CANMET Energy Technology Centre (CETC) R&D Oxyfuel Combustion for CO_2 Capture**
Nominators: Canada (lead) and United States
This is a pilot-scale project, located in Ontario, Canada, that will demonstrate oxy-fuel combustion technology with CO_2 capture. The goal of the project is to develop energy-efficient integrated multi-pollutant control, waste management and CO_2 capture technologies for combustion-based applications and to provide information for the scale-up, design and operation of large-scale industrial and utility plants based on the oxy-fuel concept.
Recognized by the CSLF at its Melbourne meeting, September 2004

5. **CarbonNet Project**
Nominators: Australia (lead) and United States
This is a large-scale project that will implement a large-scale multi-user CO_2 capture, transport, and storage network in southeastern Australia in the Latrobe Valley. Multiple industrial and utility point sources of CO_2 will be connected via a pipeline to a site site where the CO_2 can be stored in saline aquifers in the offshore Gippsland Basin. The project initially plans to sequester approximately 1 to 5 million tonnes of CO_2 per year, with the potential to increase capacity significantly over time. The project will also include reservoir characterization and, once storage is underway, measurement, monitoring and verification (MMV) technologies.
Recognized by the CSLF at its Perth meeting, October 2012

6. **CASTOR** ***(Completed)***
Nominators: European Commission (lead), France, and Norway
This was a multifaceted project that had activities at various sites in Europe, in three main areas: strategy for CO_2 reduction, post-combustion capture, and CO_2 storage performance and risk assessment studies. The goal was to reduce the cost of post-combustion CO_2 capture and to develop and validate, in both public and private partnerships, all the innovative technologies needed to capture and store CO_2 in a reliable and safe way. The tests showed the reliability and efficiency of the post-combustion capture process.
Recognized by the CSLF at its Melbourne meeting, September 2004

7. **CCS Rotterdam Project**
Nominators: Netherlands (lead) and Germany
This project will implement a large-scale "CO_2 Hub" for capture, transport, utilization, and storage of CO_2 in the Rotterdam metropolitan area. The project is part of the Rotterdam Climate Initiative (RCI), which has a goal of reducing Rotterdam's CO_2 emissions by 50% by 2025 (as compared to 1990 levels). A "CO_2 cluster approach" will be utilized, with various point sources (e.g., CO_2 captured from power plants) connected via a hub / manifold arrangement to multiple storage sites such as depleted gas fields under the North Sea. This will reduce the costs for capture, transport and storage compared to individual CCS chains. The project will also work toward developing a policy and enabling framework for CCS in the region.
Recognized by the CSLF at its London meeting, October 2009

8. **CGS Europe Project**
Nominators: Netherlands (lead) and Germany
This is a collaborative venture, involving 35 partners from participant countries in Europe, with extensive structured networking, knowledge transfer, and information exchange. A goal of the project is to create a durable network of experts in CO_2 geological storage and

a centralized knowledge base which will provide an independent source of information for European and international stakeholders. The CGS Europe Project is intended to provide an information pathway toward large-scale implementation of CO_2 geological storage throughout Europe. This is intended to be a three-year project, starting in November 2011, and has received financial support from the European Commission's 7th Framework Programme (FP7).
Recognized by the CSLF at its Beijing meeting, September 2011

9. **China Coalbed Methane Technology/CO_2 Sequestration Project** ***(Completed)***
Nominators: Canada (lead), United States, and China
This pilot-scale project successfully demonstrated that coal seams in the anthracitic coals of Shanxi Province of China are permeable and stable enough to absorb CO_2 and enhance methane production, leading to a clean energy source for China. The project evaluated reservoir properties of selected coal seams of the Qinshui Basin of eastern China and carried out field testing at relatively low CO_2 injection rates. The project recommendation was to proceed to full scale pilot test at south Qinshui, as the prospect in other coal basins in China is good.
Recognized by the CSLF at its Berlin meeting, September 2005

10. **CO_2 Capture Project – Phase 2** ***(Completed)***
Nominators: United Kingdom (lead), Italy, Norway, and United States
This pilot-scale project continued the development of new technologies to reduce the cost of CO_2 separation, capture, and geologic storage from combustion sources such as turbines, heaters and boilers. These technologies will be applicable to a large fraction of CO_2 sources around the world, including power plants and other industrial processes. The ultimate goal of the entire project is to reduce the cost of CO_2 capture from large fixed combustion sources by 20-30%, while also addressing critical issues such as storage site/project certification, well integrity and monitoring.
Recognized by the CSLF at its Melbourne meeting, September 2004

11. **CO_2 Capture Project – Phase 3**
Nominators: United Kingdom (lead) and United States
This is a collaborative venture of seven partner companies (international oil and gas producers) plus the Electric Power Research Institute. The overall goals of the project are to increase technical and cost knowledge associated with CO_2 capture technologies, to reduce CO_2 capture costs by 20-30%, to quantify remaining assurance issues surrounding geological storage of CO_2, and to validate cost-effectiveness of monitoring technologies. The project is comprised of four areas: CO_2 Capture; Storage Monitoring & Verification; Policy & Incentives; and Communications. A fifth activity, in support of these four teams, is Economic Modeling. This third phase of the project will include at least two field demonstrations of CO_2 capture technologies and a series of monitoring field trials in order to obtain a clearer understanding of how to monitor CO_2 in the subsurface. Third phase activities began in 2009 and are expected to continue into 2013. Financial support is being provided by project consortium members.
Recognized by the CSLF at its Beijing meeting, September 2011

12. **CO2CRC Otway Project**
Nominators: Australia (lead) and United States
This is a pilot-scale project, located in southwestern Victoria, Australia, that involves transport and injection of approximately 100,000 tons of CO_2 over a two year period into a depleted natural gas well. Besides the operational aspects of processing, transport and

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injection of a CO_2-containing gas stream, the project also includes development and testing of new and enhanced monitoring, and verification of storage (MMV) technologies, modeling of post-injection CO_2 behavior, and implementation of an outreach program for stakeholders and nearby communities. Data from the project will be used in developing a future regulatory regime for CO_2 capture and storage (CCS) in Australia.
Recognized by the CSLF at its Paris meeting, March 2007

13. CO_2 Field Lab Project
Nominators: Norway (lead), France, and United Kingdom
This is a pilot-scale project, located at Svelvik, Norway, which will investigate CO_2 leakage characteristics in a well-controlled and well-characterized permeable geological formation. Relatively small amounts of CO_2 will be injected to obtain underground distribution data that resemble leakage at different depths. The resulting underground CO_2 distribution will resemble leakages and will be monitored with an extensive set of methods deployed by the project partners. The main objective is to assure and increase CO_2 storage safety by obtaining valuable knowledge about monitoring CO_2 migration and leakage. The outcomes from this project will help facilitate commercial deployment of CO_2 storage by providing the protocols for ensuring compliance with regulations, and will help assure the public about the safety of CO_2 storage by demonstrating the performance of monitoring systems.
Recognized by the CSLF at its Warsaw meeting, October 2010

14. CO_2 GeoNet
Nominators: European Commission (lead) and United Kingdom
This multifaceted project is focused on geologic storage options for CO_2 as a greenhouse gas mitigation option, and on assembling an authoritative body for Europe on geologic sequestration. Major objectives include formation of a partnership consisting, at first, of 13 key European research centers and other expert collaborators in the area of geological storage of CO_2, identification of knowledge gaps in the long-term geologic storage of CO_2, and formulation of new research projects and tools to eliminate these gaps. This project will result in re-alignment of European national research programs and prevention of site selection, injection operations, monitoring, verification, safety, environmental protection, and training standards.
Recognized by the CSLF at its Berlin meeting, September 2005

15. CO_2 Separation from Pressurized Gas Stream
Nominators: Japan (lead) and United States
This is a small-scale project that will evaluate processes and economics for CO_2 separation from pressurized gas streams. The project will evaluate primary promising new gas separation membranes, initially at atmospheric pressure. A subsequent stage of the project will improve the performance of the membranes for CO_2 removal from the fuel gas product of coal gasification and other gas streams under high pressure.
Recognized by the CSLF at its Melbourne meeting, September 2004

16. CO_2 STORE ***(Completed)***
Nominators: Norway (lead) and European Commission
This project, a follow-on to the Sleipner project, involved the monitoring of CO_2 migration (involving a seismic survey) in a saline formation beneath the North Sea and additional studies to gain further knowledge of geochemistry and dissolution processes. There were also several preliminary feasibility studies for additional geologic settings of future candidate project sites in Denmark, Germany, Norway, and the UK. The project

was successful in developing sound scientific methodologies for the assessment, planning, and long-term monitoring of underground CO_2 storage, both onshore and offshore.
Recognized by the CSLF at its Melbourne meeting, September 2004

17. CO_2 Technology Centre Mongstad Project (formerly European CO_2 Technology Centre Mongstad Project)
Nominators: Norway (lead) and Netherlands
This is a large-scale project (100,000 tonnes per year CO_2 capacity) that will establish a facility for parallel testing of amine-based and chilled ammonia CO_2 capture technologies from two flue gas sources with different CO_2 contents. The goal of the project is to reduce cost and technical, environmental, and financial risks related to large scale CO_2 capture, while allowing evaluation of equipment, materials, process configurations, different capture solvents, and different operating conditions. The project will result in validation of process and engineering design for full-scale application and will provide insight into other aspects such as thermodynamics, kinetics, engineering, materials of construction, and health / safety / environmental (HSE).
Recognized by the CSLF at its London meeting, October 2009

18. Demonstration of an Oxyfuel Combustion System *(Completed)*
Nominators: United Kingdom (lead) and France
This project, located at Renfrew, Scotland, UK, demonstrated oxyfuel technology on a full-scale 40-megawatt burner. The goal of the project was to gather sufficient data to establish the operational envelope of a full-scale oxyfuel burner and to determine the performance characteristics of the oxyfuel combustion process at such a scale and across a range of operating conditions. Data from the project is being used to develop advanced computer models of the oxyfuel combustion process, which will be utilized in the design of large oxyfuel boilers.
Recognized by the CSLF at its London meeting, October 2009

19. Dynamis *(Completed)*
Nominators: European Commission (lead), and Norway
This was the first phase of the multifaceted European Hypogen program, which will result in the construction and operation of an advanced commercial-scale power plant with hydrogen production and CO_2 management. The overall aim is for operation and validation of the power plant during the 2012-2015 timeframe. The Dynamis project assessed the various options for large-scale hydrogen production while focusing on the technological, economic, and societal issues.
Recognized by the CSLF at its Cape Town meeting, April 2008

20. ENCAP *(Completed)*
Nominators: European Commission (lead), France, and Germany
This multifaceted research project consisted of six sub-projects: Process and Power Systems, Pre-Combustion Decarbonization Technologies, O_2/ CO_2 Combustion (Oxy-fuel) Boiler Technologies, Chemical Looping Combustion (CLC), High-Temperature Oxygen Generation for Power Cycles, and Novel Pre-Combustion Capture Concepts. The goals were to develop promising pre-combustion CO_2 capture technologies (including O_2/ CO_2 combustion technologies) and propose the most competitive demonstration power plant technology, design, process scheme, and component choices. All sub-projects were successfully completed by March 2009.
Recognized by the CSLF at its Berlin meeting, September 2005

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21. Fort Nelson Carbon Capture and Storage Project

Nominators: Canada (lead) and United States

This is a large-scale project in northeastern British Columbia, Canada, which will permanently sequester approximately two million tonnes per year CO_2 emissions from a large natural gas-processing plant into deep saline formations of the Western Canadian Sedimentary Basin (WCSB). Goals of the project are to verify and validate the technical and economic feasibility of using brine-saturated carbonate formations for large-scale CO_2 injection and demonstrate that robust monitoring, verification, and accounting (MVA) of a brine-saturated CO_2 sequestration project can be conducted cost-effectively. The project will also develop appropriate tenure, regulations, and MVA technologies to support the implementation of future large-scale sour CO_2 injection into saline-filled deep carbonate reservoirs in the northeast British Columbia area of the WCSB.

Recognized by the CSLF at its London meeting, October 2009

22. Frio Project *(Completed)*

Nominators: United States (lead) and Australia

This pilot-scale project demonstrated the process of CO_2 sequestration in an on-shore underground saline formation in the eastern Texas region of the United States. This location was ideal, as very large scale sequestration may be needed in the area to significantly offset anthropogenic CO_2 releases. The project involved injecting relatively small quantities of CO_2 into the formation and monitoring its movement for several years thereafter. The goals were to verify conceptual models of CO_2 sequestration in such geologic structures; demonstrate that no adverse health, safety or environmental effects will occur from this kind of sequestration; demonstrate field-test monitoring methods; and develop experience necessary for larger scale CO_2 injection experiments.

Recognized by the CSLF at its Melbourne meeting, September 2004

23. Geologic CO_2 Storage Assurance at In Salah, Algeria

Nominators: United Kingdom (lead) and Norway

This multifaceted project will develop the tools, technologies, techniques and management systems required to cost-effectively demonstrate, safe, secure, and verifiable CO_2 storage in conjunction with commercial natural gas production. The goals of the project are to develop a detailed dataset on the performance of CO_2 storage; provide a field-scale example on the verification and regulation of geologic storage systems; test technology options for the early detection of low-level seepage of CO_2 out of primary containment; evaluate monitoring options and develop guidelines for an appropriate and cost-effective, long-term monitoring methodology; and quantify the interaction of CO_2 re-injection and hydrocarbon production for long-term storage in oil and gas fields.

Recognized by the CSLF at its Berlin meeting, September 2005

24. Gorgon CO_2 Injection Project

Nominators: Australia (lead), Canada, and United States

This is a large-scale project that will store approximately 120 million tonnes of CO_2 in a water-bearing sandstone formation two kilometers below Barrow Island, off the northwest coast of Australia. The CO_2 stored by the project will be extracted from natural gas being produced from the nearby Gorgon Field and injected at approximately 3.5 to 4 million tonnes per year. There is an extensive integrated monitoring plan, and the objective of the project is to demonstrate the safe commercial-scale application of greenhouse gas storage technologies at a scale not previously attempted.

Recognized by the CSLF at its Warsaw meeting, October 2010

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25. IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project *(Completed)*

Nominators: Canada and United States (leads) and Japan

This is a large-scale project that will utilize CO_2 for enhanced oil recovery (EOR) at a Canadian oil field. The goal of the project is to determine the performance and undertake a thorough risk assessment of CO_2 storage in conjunction with its use in enhanced oil recovery. The work program will encompass four major technical themes of the project: geological integrity; wellbore injection and integrity; storage monitoring methods; and risk assessment and storage mechanisms. Results from these technical themes, when integrated with policy research, will result in a Best Practices Manual for future CO_2 Enhanced Oil Recovery projects.

Recognized by the CSLF at its Melbourne meeting, September 2004

26. Illinois Basin – Decatur Project

Nominators: United States (lead) and United Kingdom

This is a large-scale research project that will geologically store up to 1 million metric tons of CO_2 over a 3-year period. The CO_2 is being captured from the fermentation process used to produce ethanol at an industrial corn processing complex in Decatur, Illinois, in the United States. After three years, the injection well will be sealed and the reservoir monitored using geophysical techniques. Monitoring, verification, and accounting (MVA) efforts include tracking the CO_2 in the subsurface, monitoring the performance of the reservoir seal, and continuous checking of soil, air, and groundwater both during and after injection. The project focus is on demonstration of CCS project development, operation, and implementation while demonstrating CCS technology and reservoir quality.

Recognized by the CSLF at its Perth meeting, October 2012

27. Illinois Industrial Carbon Capture and Storage Project

Nominators: United States (lead) and France

This is a large-scale commercial project that will collect up to 3,000 tonnes per day of CO_2 for deep geologic storage. The CO_2 is being captured from the fermentation process used to produce ethanol at an industrial corn processing complex in Decatur, Illinois, in the United States. The goals of the project are to design, construct, and operate a new CO_2 collection, compression, and dehydration facility capable of delivering up to 2,000 tonnes of CO_2 per day to the injection site; to integrate the new facility with an existing 1,000 tonnes of CO_2 per day compression and dehydration facility to achieve a total CO_2 injection capacity of 3,000 tonnes per day (or one million tonnes annually); to implement deep subsurface and near-surface MVA of the stored CO_2; and to develop and conduct an integrated community outreach, training, and education initiative.

Recognized by the CSLF at its Perth meeting, October 2012

28. ITC CO_2 Capture with Chemical Solvents Project

Nominators: Canada (lead) and United States

This is a pilot-scale project that will demonstrate CO_2 capture using chemical solvents. Supporting activities include bench and lab-scale units that will be used to optimize the entire process using improved solvents and contactors, develop fundamental knowledge of solvent stability, and minimize energy usage requirements. The goal of the project is to develop improved cost-effective technologies for separation and capture of CO_2 from flue gas.

Recognized by the CSLF at its Melbourne meeting, September 2004

29. Kemper County Energy Facility

Nominators: United States (lead) and Canada

This commercial-scale CCS project, located in east-central Mississippi in the United States, will capture approximately 3 million tonnes of CO_2 per year from integrated gasification combined cycle (IGCC) power plant, and will include pipeline transportation of approximately 60 miles to an oil field where the CO_2 will sold for enhanced oil recovery (EOR). The commercial objectives of the project are large-scale demonstration of a next-generation gasifier technology for power production and utilization of a plentiful nearby lignite coal reserve. Approximately 65% of the CO_2 produced by the plant will be captured and utilized.

Recognized by the CSLF at its Washington meeting, November 2013

30. Ketzin Test Site Project (formerly CO_2 SINK) ***(Completed)***

Nominators: European Commission (lead) and Germany

This is a pilot-scale project that tested and evaluated CO_2 capture and storage at an existing natural gas storage facility and in a deeper land-based saline formation. A key part of the project was monitoring the migration characteristics of the stored CO_2. The project was successful in advancing the understanding of the science and practical processes involved in underground storage of CO_2 and provided real case experience for use in development of future regulatory frameworks for geological storage of CO_2.

Recognized by the CSLF at its Melbourne meeting, September 2004

31. Lacq Integrated CCS Project

Nominators: France (lead) and Canada

This is an intermediate-scale project that will test and demonstrate an entire integrated CCS process, from emissions source to underground storage in a depleted gas field. The project will capture and store 60,000 tonnes per year of CO_2 for two years from an oxyfuel industrial boiler in the Lacq industrial complex in southwestern France. The goal is demonstrate the technical feasibility and reliability of the integrated process, including the oxyfuel boiler, at an intermediate scale before proceeding to a large-scale demonstration. The project will also include geological storage qualification methodologies, as well as monitoring and verification techniques, to prepare future larger-scale long term CO_2 storage projects.

Recognized by the CSLF at its London meeting, October 2009

32. MRCSP Development Phase Project

Nominators: United States (lead) and Canada

This is a large-scale CO_2 storage project, located in Michigan and nearby states in the northern United States that will, over its four-year duration, inject a total of one million tonnes of CO_2 into different types of oil and gas fields in various lifecycle stages. The project will include collection of fluid chemistry data to better understand geochemical interactions, development of conceptual geologic models for this type of CO_2 storage, and a detailed accounting of the CO_2 injected and recycled. Project objectives are to assess storage capacities of these oil and gas fields, validate static and numerical models, identify cost-effective monitoring techniques, and develop system-wide information for further understanding of similar geologic formations. Results obtained during this project are expected to provide a foundation for validating that CCS technologies can be commercially deployed in the northern United States.

Recognized by the CSLF at its Washington meeting, November 2013

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33. Quest CCS Project

Nominators: Canada (lead), United Kingdom, and United States

This is a large-scale project, located at Fort Saskatchewan, Alberta, Canada, with integrated capture, transportation, storage, and monitoring, which will capture and store up to 1.2 million tonnes per year of CO_2 from an oil sands upgrading unit. The CO_2 will be transported via pipeline and stored in a deep saline aquifer in the Western Sedimentary Basin in Alberta, Canada. This is a fully integrated project, intended to significantly reduce the carbon footprint of the commercial oil sands upgrading facility while developing detailed cost data for projects of this nature. This will also be a large-scale deployment of CCS technologies and methodologies, including a comprehensive measurement, monitoring and verification (MMV) program.

Recognized by the CSLF at its Warsaw meeting, October 2010

34. Regional Carbon Sequestration Partnerships

Nominators: United States (lead) and Canada

This multifaceted project will identify and test the most promising opportunities to implement sequestration technologies in the United States and Canada. There are seven different regional partnerships, each with their own specific program plans, which will conduct field validation tests of specific sequestration technologies and infrastructure concepts; refine and implement (via field tests) appropriate measurement, monitoring and verification (MMV) protocols for sequestration projects; characterize the regions to determine the technical and economic storage capacities; implement and continue to research the regulatory compliance requirements for each type of sequestration technology; and identify commercially available sequestration technologies ready for large scale deployment.

Recognized by the CSLF at its Berlin meeting, September 2005

35. Regional Opportunities for CO_2 Capture and Storage in China ***(Completed)***

Nominators: United States (lead) and China

This project characterized the technical and economic potential of CO_2 capture and storage technologies in China. The goals were to compile key characteristics of large anthropogenic CO_2 sources (including power generation, iron and steel plants, cement kilns, petroleum and chemical refineries, etc.) as well as candidate geologic storage formations, and to develop estimates of geologic CO_2 storage capacities in China. The project found 2,300 gigatons of potential CO_2 storage capacity in onshore Chinese basins, significantly more than previous estimates. Another important finding is that the heavily developed coastal areas of the East and South Central regions appear to have less access to large quantities of onshore storage capacity than many of the inland regions. These findings present the possibility for China’s continued economic growth with coal while safely and securely reducing CO_2 emissions to the atmosphere.

Recognized by the CSLF at its Berlin meeting, September 2005

36. Rotterdam Opslag en Afvang Demonstratieproject (ROAD)

Nominators: Netherlands (lead) and the European Commission

This is a large-scale integrated project, located near the city of Rotterdam, Netherlands, which includes CO_2 capture from a coal-fueled power plant, pipeline transportation of the CO_2, and offshore storage of the CO_2 in a depleted natural gas reservoir beneath the seabed of the North Sea (approximately 20 kilometers from the power plant). The goal of the project is to demonstrate the feasibility of a large-scale, integrated CCS project while addressing the various technical, legal, economic, organizational, and societal aspects of the project. ROAD will result in the capture and storage of approximately 1.1 million

tonnes of CO_2 annually over a five year span starting in 2015. Subsequent commercial operation is anticipated, and there will be continuous knowledge sharing. This project has received financial support from the European Energy Programme for Recovery (EEPR), the Dutch Government, and the Global CCS Institute, and is a component of the Rotterdam Climate Initiative CO_2 Transportation Network.
Recognized by the CSLF at its Beijing meeting, September 2011

37. SaskPower Integrated CCS Demonstration Project at Boundary Dam Unit 3
Nominators: Canada (lead) and the United States
This is a large-scale project, located in the southeastern corner of Saskatchewan Province in Canada, which will be the first application of full stream CO_2 recovery from flue gas of a 139 megawatt coal-fueled power plant unit. A major goal is to demonstrate that a post-combustion CO_2 capture retrofit on a commercial power plant can achieve optimal integration with the thermodynamic power cycle and with power production at full commercial scale. The project will result in capture of approximately one million tonnes of CO_2 per year, which will be sold to oil producers for enhanced oil recovery (EOR) and injected into a deep saline aquifer.
Recognized by the CSLF at its Beijing meeting, September 2011

38. SECARB Early Test at Cranfield Project
Nominators: United States (lead) and Canada
This is a large-scale project, located in southwestern Mississippi in the United States, which involves transport, injection, and monitoring of approximately one million tonnes of CO_2 per year into a deep saline reservoir associated with a commercial enhanced oil recovery operation, but the focus of this project will be on the CO_2 storage and monitoring aspects. The project will promote the building of experience necessary for the validation and deployment of carbon sequestration technologies in the United States, and will increase technical competence and public confidence that large volumes of CO_2 can be safely injected and stored. Components of the project also include public outreach and education, site permitting, and implementation of an extensive data collection, modeling, and monitoring plan. This "early" test will set the stage for a subsequent large-scale integrated project that will involve post-combustion CO_2 capture, transportation via pipeline, and injection into a deep saline formation.
Recognized by the CSLF at its Warsaw meeting, October 2010

39. SECARB Phase III Anthropogenic Test and Plant Barry CCS Project
Nominators: United States (lead), Japan, and Canada
This large-scale fully-integrated CCS project, located in southeastern Alabama in the United States, brings together components of CO_2 capture, transport, and geologic storage, including monitoring, verification, and accounting of the stored CO_2. A flue gas slipstream from a power plant equivalent to approximately 25 megawatts of power production is being diverted to allow large-scale demonstration of a new amine-based process that can capture approximately 550 tons of CO_2 per day. A 19 kilometer pipeline has also been constructed, as part of the project, for transport of the CO_2 to a deep saline storage site. Objectives of the project are to gain knowledge and experience in operation of a fully integrated CCS large-scale process, to conduct reservoir modeling and test CO_2 storage mechanisms for the types of geologic storage formations that exist along the Gulf Coast of the United States, and to test experimental CO_2 monitoring technologies.
Recognized by the CSLF at its Washington meeting, November 2013

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40. South West Hub Geosequestration Project

Nominators: Australia (lead), United States, and Canada

This is a large-scale project that will implement a large-scale "CO_2 Hub" for multi-user capture, transport, utilization, and storage of CO_2 in southwestern Australia near the city of Perth. Several industrial and utility point sources of CO_2 will be connected via a pipeline to a site for safe geologic storage deep underground in the Triassic Lesueur Sandstone Formation. The project initially plans to sequester 2.4 million tonnes of CO_2 per year and has the potential for capturing approximately 6.5 million tonnes of CO_2 per year. The project will also include reservoir characterization and, once storage is underway, MMV technologies.

Recognized by the CSLF at its Perth meeting, October 2012

41. Uthmaniyah CO_2-EOR Demonstration Project

Nominators: Saudi Arabia (lead) and United States

This large-scale project, located in the Eastern Province of Saudi Arabia, will capture and store approximately 800,000 tonnes of CO_2 per year from a natural gas production and processing facility, and will include pipeline transportation of approximately 70 kilometers to the injection site (a small flooded area in the Uthmaniyah Field). The objectives of the project are determination of incremental oil recovery (beyond water flooding), estimation of sequestered CO_2, addressing the risks and uncertainties involved (including migration of CO_2 within the reservoir), and identifying operational concerns. Specific CO_2 monitoring objectives include developing a clear assessment of the CO_2 potential (for both EOR and overall storage) and testing new technologies for CO_2 monitoring.

Recognized by the CSLF at its Washington meeting, November 2013

42. Zama Acid Gas EOR, CO_2 Sequestration, and Monitoring Project

Nominators: Canada (lead) and United States

This is a pilot-scale project that involves utilization of acid gas (approximately 70% CO_2 and 30% hydrogen sulfide) derived from natural gas extraction for enhanced oil recovery. Project objectives are 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. Acid gas injection was initiated in December 2006 and will result in sequestration of about 25,000 tons (or 375 million cubic feet) of CO_2 per year.

Recognized by the CSLF at its Paris meeting, March 2007

43. Zero Emission Porto Tolle Project (ZEPT)

Nominators: Italy (lead) and European Commission

This is a large-scale project, located in northeastern Italy, which will demonstrate post-combustion CCS on 40% of the flue gas from one of the three 660 megawatt units of the existing Porto Tolle Power Plant (which is being converted from heavy oil fuel to coal). The goal of the project is to demonstrate industrial application of CO_2 capture and geological storage for the power sector at full commercial scale. The demonstration plant will be operated for an extended period (approx. 10 years) in order to fully demonstrate the technology on an industrial scale, clarify the real costs of CCS, and prove the retrofit option for high-efficiency coal fired units which will be built (or replaced) in the coming 10-15 years. Storage of approx. 1 million tonnes per year of CO_2 will take place in a deep saline aquifer beneath the seabed of the Adriatic Sea approx. 100 kilometers from the project site.

Recognized by the CSLF at its Beijing meeting, September 2011

Note: "Lead Nominator" in this usage indicates the CSLF Member which proposed the project.