2014 CSLF ANNUAL MEETING

Warsaw, Poland

October 27-30, 2014

Carbon Sequestration Leadership Forum

www.cslforum.org

2014 CSLF ANNUAL MEETING DOCUMENTS BOOK

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Carbon Sequestration Leadership Forum

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2014 CSLF Annual Meeting
Warsaw, Poland
27-30 October 2014

	Monday 27 October Ministry of Economy	Tuesday 28 October Ministry of Economy	Wednesday 29 October Bełchatów	Thursday 30 October Ministry of Economy
Morning		**Meeting Registration** *Foyer outside Rooms "A-B-C"* *08:00-09:00* **CSLF Technical Group** *Rooms "A-B-C"* *09:00-12:30*	**Visit to Bełchatów Power Plant** *Bus transportation provided, departure 08:00 from pl. Trzech Krzyży (in front of Ministry of Economy)* Note: Site visit will include a presentation about CCS-ready unit of the power plant	**Meeting Registration** *Foyer outside Rooms "A-B-C"* *08:00-09:00* **CSLF Policy Group** *Rooms "A-B-C"* *09:00-12:00*
		Lunch *Sheraton Hotel* *12:00-13:45*	Site Visit includes Lunch (hosted by PGE S.A.)	**Lunch** *Sheraton Hotel* *12:00-13:45*
Afternoon	**Meeting Registration** *Foyer outside Rooms "A-B-C"* *13:00-17:00* **CSLF Projects Interaction & Review Team (PIRT)** ***Room "C"*** *14:00-16:00*	**CSLF Technical Group** *Rooms "A-B-C"* *13:45-16:30*	**Visit to Bełchatów Power Plant** *Bus transportation provided, return time approx. 17:30*	**CSLF Policy Group** *Rooms "A-B-C"* *13:45-16:00*
Evening			**Reception / Dinner** *Sheraton Hotel* *Time TBA*	

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

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CSLF-P-2014-04
Draft: 17 October 2014
Prepared by CSLF Secretariat

DRAFT AGENDA
CSLF Policy Group Meeting
Ministry of Economy
Warsaw, Poland
October 30, 2014

08:00-09:00 **Meeting Registration**
Foyer outside Rooms "A-B-C"

09:00-10:45 **Policy Group Meeting**
Rooms "A-B-C"

1. **Welcome and Opening Statement**
   Christopher Smith, Policy Group Chair, United States

2. **Host Country Welcome**
   Tomasz Dąbrowski, Director, Energy Department, Ministry of Economy, Poland

3. **Introduction of Delegates**
   Delegates

4. **Adoption of Agenda**
   Christopher Smith, Policy Group Chair, United States

5. **Review and Approval of Minutes from London** — CSLF-P-2014-03
   Christopher Smith, Policy Group Chair, United States

6. **Review of London Meeting Action Items**
   Adam Wong, CSLF Secretariat

7. **Recent and Current CCS Issues**
   - Report on UN Climate Leaders' Summit
   - Report on UNFCCC Meeting

   Juho Lipponen, IEA
   Andrew Purvis, Global CCS Institute
   Delegates

8. **Update from CSLF Technical Group**
   Trygve Riis, Technical Group Chair, Norway

9. **Discussion of Exploratory Committee Work Plan:**
   a. **Supporting Development of 2nd and 3rd Generation CCS Technologies** — CSLF-P-2014-05
      Trygve Riis, Technical Group Chair, Norway
      Kathryn Gagnon, Canada
      Tone Skogen, Norway
      Delegates

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10:45-11:00 Refreshment Break
Foyer outside Rooms "A-B-C"

11:00-12:00 Continuation of Meeting

b. Global Collaboration on Large-Scale CCS Projects
Jarad Daniels, United States
Sizhen Peng, China
Delegates

12:00-13:45 Lunch
Sheraton Hotel

13:45-15:30 Continuation of Meeting

c. Financing for CCS Projects
Bernard Frois, France
Delegates

d. Communications CSLF-P-2014-06
Juho Lipponen, International Energy Agency
Andrew Purvis, Global CCS Institute
Delegates

15:30-15:45 Refreshment Break
Foyer outside Rooms "A-B-C"

15:45-17:00 Continuation of Meeting

10. Stakeholder Recommendations to CSLF
Barry Worthington, United States Energy Association
Other Stakeholders TBD
Delegates

11. CSLF Input to the next CEM Meeting
Jarad Daniels, United States
Delegates

12. Planning for 2015 CSLF Meetings
Adam Wong, CSLF Secretariat
Delegates

13. Action Items and Next Steps
Adam Wong, CSLF Secretariat

14. Open Discussion and New Business
Delegates

15. Closing Remarks / Adjourn
Christopher Smith, Policy Group Chair, United States

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.

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Carbon Sequestration Leadership Forum

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CSLF-T-2014-06
Draft: 16 October 2014
Prepared by CSLF Secretariat

DRAFT AGENDA
CSLF Technical Group Meeting

Ministry of Economy of Poland
Warsaw, Poland
October 28, 2014

08:00-09:00 **Meeting Registration**
Foyer outside Rooms "A-B-C"

09:00-10:30 **Technical Group Meeting**
Rooms "A-B-C"

1. **Welcome and Opening Statement**
Trygve Riis, Technical Group Chair, Norway

2. **Host Country Welcome**
Małgorzata Mika-Bryska, Deputy Director, Energy Department, Ministry of Economy, Poland

3. **Introduction of Delegates**
Delegates

4. **Adoption of Agenda**
Trygve Riis, Technical Group Chair, Norway

5. **Review and Approval of Minutes from Seoul** CSLF-T-2014-05
Trygve Riis, Technical Group Chair, Norway

6. **Report from Secretariat**
   - Review of Seoul Meeting Action Items
   - Highlights from March 2014 Technical Group meeting

Richard Lynch, CSLF Secretariat

7. **CCS in Poland**
Elżbieta Wróblewska, Coordinator, Unit of New Technologies and Environmental Protection, Energy Department, Ministry of Economy, Poland

8. **Update from the IEA Greenhouse Gas R&D Programme**
Tim Dixon, IEA GHG

10:30-10:45 **Refreshment Break**
Foyer outside Rooms "A-B-C"

10:45-12:00 **Continuation of Meeting**

9. **Report from Projects Interaction and Review Team**
Clinton Foster, PIRT Chair, Australia

10. **Progress Report on CSLF Technology Roadmap** CSLF-T-2014-07
Clinton Foster, PIRT Chair, Australia

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11. Report from Review of CO_2 Storage Efficiency in Deep Saline Aquifers Task Force
Presented by: Richard Lynch, CSLF Secretariat

12. Report from Sub-Seabed Storage of CO_2 Task Force
Presented by: John Litynski, United States

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

14. Appraisal of Proposed Technical Group Action concerning Energy Penalty Reduction
Philip Sharman, United Kingdom

12:00-13:45 Lunch
Sheraton Hotel

13:45-15:00 Continuation of Meeting

15. Review of Technical Group Action Plan CSLF-T-2014-08
Trygve Riis, Technical Group Chair, Norway

16. Review of Project Nominated for CSLF Recognition: Norcem CO_2 Capture Project
Liv Bjerge, Project Manager, Norcem CO_2 Capture Project

17. Collaboration with CSLF Policy Group CSLF-P-2014-05
Trygve Riis, Technical Group Chair, Norway

15:00-15:15 Refreshment Break
Foyer outside Rooms "A-B-C"

15:15-16:00 Continuation of Meeting

18. Update on Future CSLF Meetings
Richard Lynch, CSLF Secretariat

19. Open Discussion and New Business
Delegates

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

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

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Draft: 17 October 2014
Prepared by CSLF Secretariat

Agenda

CSLF PROJECTS INTERACTION AND REVIEW TEAM (PIRT)

Ministry of Economy
Warsaw, Poland
27 October 2014

Room "C"
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 Seoul PIRT Meeting**
   Clinton Foster, PIRT Chair, Australia

4. **Report from Secretariat**
   - Review of Action Items from Seoul Meeting
   - CSLF Technology Roadmap Progress Report
   - Outcomes from March 2014 Technology Workshop
   - Update on CSLF Recognized Projects

   Richard Lynch, CSLF Secretariat

5. **Review and Approval of Project Proposed for CSLF Recognition: Norcem CO_2 Capture Project**
   Liv Bjerge, Project Manager, Norcem CO_2 Capture Project

6. **Report on PIRT Activities concerning Knowledge-Sharing**
   Clinton Foster, PIRT Chair, Australia

7. **Future PIRT Activities**
   - Technology Workshops
   - TRM Progress Reports
   - 2017 TRM

   Clinton Foster, PIRT Chair, Australia
   Meeting Attendees

8. **Action Items and Next Steps**
   Richard Lynch, CSLF Secretariat

9. **Closing Comments / Adjourn**
   Clinton Foster, PIRT Chair, Australia

Minutes of the Carbon Sequestration Leadership Forum (CSLF)
Policy Group Meeting

London, United Kingdom
Thursday, 5 June, 2014

LIST OF ATTENDEES

Chair: Christopher Smith (United States)

Policy Group Delegates

Brazil: Tulio Andrade
Canada: Geoff Murphy, Stefan Bachu
China: Jiutian Zhang
European Commission: Ilinca Balan, Jeroen Schuppers
France: Bernard Frois
Japan: Takashi Kawabata, Ryozo Tanaka
Mexico: William Jensen Diaz
Norway: Tone Skogen, Fredrik Netland, Trygve Riis
South Africa (via Skype): Gina Downes
United Kingdom: Amy Clemitshaw, Tony Ripley, Jonathan Hood
United States: Julio Friedmann

Representatives of Allied Organizations
IEA CCS Unit: Juho Lipponen, Tristan Stanley
Global CCS Institute: Andrew Purvis

CSLF Secretariat
Jarad Daniels

Observers
Allan Baker, Société Générale, France
Carole Chapman, Department of Energy & Climate Change (DECC), United Kingdom
Jeff Chapman, CCS Association, United Kingdom
Edward Heartney, U.S. Embassy London, United States
Ashley Ibbett, Department of Energy & Climate Change (DECC), United Kingdom
Peter Radgen, E.ON, Germany
Robert Van Voorhees, Carbon Sequestration Council, United States
Ruth Van Voorhees, EcoReg Matters Ltd., United States
Barry Worthington, United States Energy Association, United States

1. Welcome and Opening Statement. On behalf of the CSLF Policy Group Chair Christopher Smith, Julio Friedmann, United States, called the meeting to order.

2. Host Country Welcome. Amy Clemitshaw, Head of CCS Policy, Department of Energy & Climate Change (DECC), United Kingdom, welcomed the attendees and provided the host country remarks.

3. Introduction of Delegates. Policy Group delegates present for the meeting introduced themselves. Eleven of the twenty-three CSLF members were present, including representatives from Brazil, Canada, China, the European Commission, France, Japan, Mexico, Norway, South Africa, the United Kingdom, and the United States. Observers representing the IEA CCS Unit and the Global CCS Institute were also present.

4. Adoption of Agenda. The Agenda was adopted without change.

5. Approval of Minutes from Washington Meeting. The Minutes from the November 2013 Policy Group Meeting in Washington, D.C. were approved without change.

6. Review of Action Items from Washington Meeting. Jarad Daniels, Director, CSLF Secretariat, provided a brief summary of the action items from the November 2013 Washington Policy Group Meeting. All action items have been completed or are in process.

7. Update from CSLF Technical Group. Trygve Riis, Technical Group Chair, provided an update from the CSLF Technical Group, including a summary of the recent Technical Group Meeting in Seoul, Korea, in March 2014.

8. Discussion of Exploratory Committee Work Plan. Approximately one hour was spent discussing each topic area identified by the CSLF Exploratory Committee, established at the November 2013 CSLF Ministerial Meeting in Washington, and tasked to identify topics of interest from which an action plan can be developed.

A. **Financing for CCS Projects:** Bernard Frois, France, summarized his work to conduct a series of workshops and discussions on the business case for CCS, including the recent Financial Roundtable hosted by Société Générale in Paris on 23 May 2014. It was agreed that outcomes and recommendations from such workshops should be captured and disseminated to maximize value of these efforts, especially given that in the last two years there has been a large growth of interest in CCS from financial institutions. This interest from financial institutions has been driven by “good news” stories on the construction and completion of large scale CCS plants worldwide. It was stated that operating CCS plants, which employ a range of technologies, now exist and has started to create the “precedent” base required by the financial community to get comfortable with CCS as a new industry. Dr. Frois will draft a work plan on how to best continue engaging the finance community, with the next workshop planned to focus on CCS deployment in Asia, to be hosted in Washington, D.C. later in 2014.

B. **Communications:** Andrew Purvis, Global CCS Institute, presented the Communications Task Force Work Plan. Their mandate was presented as providing a focal point for coordinating consistent messaging on CCS internationally with organizations such as the IEA and the Global CCS Institute, enabling key messages to be delivered more frequently than through bi-annual CSLF Ministerial meetings, and evaluating the potential to communicate directly with other key audiences. Much discussion ensued regarding potential audiences, outreach opportunities, key messages, appropriate communication mechanisms, etc. The Communications Task Force was asked to draft a Communications Action Plan based on input received during the meeting. Specifically, it was agreed that key messages should come from within the CSLF, the Task Force should recommend prioritized target organizations to engage, and draft a CSLF procedure on how to engage other organizations (e.g. provide standardized CSLF communication messages to Ministers to deliver, develop a procedure for CSLF representatives to speak on behalf of the CSLF as opportunities arise, etc.)

C. **Global Collaboration on Large–Scale CCS Projects:** Julio Friedmann, United States, presented a phased approach to look at what the CSLF can do to progress large scale projects and the sharing of large scale project data. The proposed scope was to: 1) promote and coordinate the sharing of knowledge gained from large-scale CO2 saline storage projects carried out in CSLF member countries, and 2) Coordinate a process to identify and select a large-scale CO_2 saline storage site suitable for advancing the CO2 storage state-of-the art. After good discussion, it was suggested that this effort continue to explore potential collaboration options and develop an action plan to 1) determine potential government interest in participating/supporting such efforts, 2) engage major projects that currently exist to determine opportunities to leverage existing project data and capital, and explore the potential for a collaborative effort under the CSLF to add additional functionality in the future, and 3) better refine the goals and key metrics we are striving for. Co-leads China and the US were requested to refine the action plan based on input from the meeting and information gained from planned discussions with interested parties.

D. **Supporting Development of 2nd and 3rd Generation CCS Technologies:** Trygve Riis, Norway, presented the task force's views on what and how efforts should be taken to better understand the role of 2nd and 3rd generation technologies for CCS deployment, policies and approaches that can stimulate advanced technology development, and possible actions that the CSLF could take to advance technology development. It was noted that the CSLF Technical group should map and identify 2nd and 3rd generation technologies under consideration in CSLF member countries and identify technologies that may mature in the 2020-2030 timeframe. It was suggested that the CCS Test Centre Network & the CSLF Technical Group should use existing networks to map the potential for testing promising technologies. In parallel, the Policy Group should map initiatives and funding mechanisms for 2nd and 3rd generation technologies in CSLF member countries, and prepare a policy document on how to accelerate implementation of 2nd and 3rd generation CO_2 capture technologies, including investigating new mechanisms that may be possible and highlighting opportunities for international collaborations.

It was agreed that each of the above task forces should draft detailed action plans and deliver them to the CSLF Secretariat approximately two months after the meeting, such that the Secretariat can distribute the draft action plans to all members, and solicit feedback in advance of the next Policy Group meeting.

9. Proposed Policy Group Activity concerning Policy, Legal, and Regulatory Challenges for Transitioning from CO2-EOR to CCS. Stefan Bachu, Canada, presented on behalf of the Technical Group Task Force on Technical Challenges in the Transition from CO_2-EOR to CCS, including the recommendation that the Policy Group establish a Task Force to examine and address ""Policy, Legal and Regulatory Challenges in the Transitioning from CO_2-EOR to CCS." Many technical and policy aspects were presented regarding the difference and similarities between deep saline storage and CO_2-EOR. It was suggested that Policy Group delegates digest Dr. Bachu's presentation and suggestions for policy topics, and provide feedback to the CSLF Secretariat, such that the conversations may continue on these topics and to see which ones get interest for further discussion.

10. Review of Stakeholder Recommendations to CSLF. Barry Worthington, United States Energy Association, briefly reviewed the stakeholder recommendations from the last CSLF Ministerial Meeting in Washington, D.C., and noted that some of the stakeholders would like to be more engaged with the CSLF. The CSLF Secretariat took the action item to work with Mr. Worthington and USEA to ensure that moving forward, stakeholders are more engaged. Mr. Worthington also recommended that the CSLF should consider hiring communication professionals to help with reinvigorated outreach and communication efforts, and it was decided that the Communications Task Force should investigate this.

11. Planning for 2014 CSLF Annual Meeting. Jarad Daniels, Director, CSLF Secretariat, stated that no country had yet volunteered to host the 2014 CSLF Annual Meeting, and requested that each country inform the CSLF Secretariat of their intention within the next two weeks. Christopher Smith, United States, noted that he strongly preferred to have the next CSLF meeting hosted in Europe to bring focus to the potential for CCS in Europe.

12. Action Items and Next Steps. Jarad Daniels, Director, CSLF Secretariat, summarized the results of the day's discussions and noted that each Task Force has the action to draft a short working paper on their plans forward, and to provide that to the CSLF Secretariat within two months. The CSLF Secretariat will then circulate the materials for review and feedback in advance of the next CSLF meeting. Each country has the action to inform the CSLF Secretariat within the next two weeks if they would like to host the next CSLF meeting.

13. Open Discussion and New Business. No new business was discussed.

14. Closing Remarks / Adjourn. Christopher Smith, United States, closed the meeting by thanking all of the participants for their input, and by thanking the government of the United Kingdom for hosting the event.

Carbon Sequestration Leadership Forum
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CSLF-P-2014-05
16 October 2014

POLICY GROUP

Supporting Development of 2nd and 3rd Generation Carbon Capture Technologies

Background

At the June 2014 CSLF Policy Group Meeting in London, there was consensus that the Policy Group's overall Action Plan would consist of four main areas of interest. One of these areas is "Supporting Development of 2nd and 3rd Generation CCS Technologies" and to that end the Policy Group established a joint Policy -Technical Working Group that was tasked to develop a draft work plan.

This paper, prepared by the Working Group, provides a description of what specific activities should comprise a work plan in this area. **This document should be considered a work-in-progress.**

Action Requested

The Policy Group is requested to review the following report from the Joint Policy-Technical Working Group.

SUPPORTING DEVELOPMENT OF 2ND AND 3RD GENERATION CARBON CAPTURE TECHNOLOGIES:

This is one topic recommended by the Exploratory Committee of the CSLF Policy Group. The Committee states that:

> "Efforts should be taken to better understand the role of 2nd and 3rd generation technologies for 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."

To achieve this, the following could be considered for joint work by the CSLF Policy and Technical Groups:

1. Map initiatives and funding mechanisms for 2nd and 3rd generation technologies in CSLF member countries. US DOE/NETL Advanced Carbon Dioxide Capture R&D Program, Norwegian CLIMIT and UK Innovation Fund for Carbon Capture Projects are examples that should be summarized for the benefit of CSLF members. Provide perspective on how these initiatives parallel with market mechanisms which would drive the adoption of these technologies. The effort should also include:
   - mapping/exploring the criteria that industry around the world may use to adopt technologies, i.e., market pull
   - identifying the specific financial challenges associated with scale-up and deployment of 2nd and 3rd generation capture technologies
   - exploring the understanding of what those challenges might, particularly if government funds are used, as well as the interest in joint funding/international collaboration

   Responsible: Policy Group.

2. Map/Identify 2nd and 3rd generation technologies under consideration in CSLF member countries, and identify technologies that may mature in the 2020 –2030 timeframe, their development plans to scale from current readiness levels to prepare for demonstration, and the major challenges facing technology development. Good starting points are technology updates from DOE/NETL Advanced Carbon Dioxide Capture R&D Program, report from UK Advanced Power generation technology Forum, projects and reports from the IEA Greenhouse Gas R&D Program, CLIMIT projects and reports from SINTEF on behalf of CSLF and TCM. Responsible: Technical Group

3. Use existing networks, e.g. the established International CCS Test Centre Network and ECCSEL, to map potential for testing 2nd and 3rd generation technologies at existing test facilities. There is knowledge from a limited number of test facilities (e.g. NCCC, CanmetENERGY and TCM) on the possibilities to test 2nd generation technologies in scale 1 - 5 MW_{th}. The list of test facilities needs to be expanded. Responsible for liaising with the networks: Technical Group

4. Prepare a Policy document on how to achieve an accelerated implementation of 2nd and 3rd generation CO_2 capture technologies. Responsible: Policy Group

Points 1 – 3 can be accomplished by compiling and summarizing information that is already available but spread on a high number of publications.

It may be useful to keep in mind what the CSLF Technical Group has said about 2nd and 3rd generation technologies in the CSLF 2013 Carbon Sequestration Technology Roadmap. The status of 2nd and 3rd generation technologies vs. the targets will help identify where actions are needed to speed up implementation of these technologies.

Definitions of 2nd and 3rd generation capture technologies

- From to the CSLF Technology Roadmap 2013:
  - 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.

There is a slightly different definition used by the CSLF Task Force on CCS Technology Opportunities and Gaps, but we will prefer to use the TRM definition.

The CSLF technology Roadmap 2013 suggests the following targets for 2nd and 3rd generation technologies:

2nd generation:
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[1], and normalized operational and maintenance (O&M) costs (fixed and non-fuel variable costs) compared to 1st generation technologies

3rd generation:
Beyond 2030: 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.

[1] 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.

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Examples of and the challenges facing 2nd and 3rd generations

	Possible 2nd and 3rd generation technology options	Implementation challenges
IGCC with pre-combustion decarbonisation	• 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	• New and more efficient air separation, e.g. membranes • Optimized boiler systems • Oxy-combustion turbines • Chemical looping combustion (CLC) - reactor systems and oxygen carriers • High pressure combustion – reactor systems to enhance efficiency.	• 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	• New solvents (e.g. amino acids, enzyme-accelerated carbonates) • 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)

Carbon Sequestration Leadership Forum

www.cslforum.org

CSLF-P-2014-06
17 October 2014

POLICY GROUP

Development of a Communications Strategy to Guide CSLF Messaging

<u>Background</u>

At the June 2014 CSLF Policy Group Meeting in London, there was consensus that the Policy Group's overall Action Plan would consist of four main areas of interest. One of these areas is "Communications" and to that end the Policy Group established a new Communications Task Force that was tasked to develop a draft Communications Work Plan.

This paper, prepared by the Communications Task Force, describes a strategy to guide the task force as it develops the Communications Work Plan.

<u>Action Requested</u>

The Policy Group is requested to review the following report from the Communications Task Force.

A Communications Brief to Engage a Communications Professional for the CSLF

Introduction

The Carbon Sequestration Leadership Forum (CSLF) is a Ministerial-level international climate change initiative that is focused on the development of improved cost-effective technologies for the separation and capture of carbon dioxide (CO2) for its transport and long-term safe storage. The CSLF is aiming to build the profile for CCS/CCUS consistent with its goals and focused on high profile international events and conferences. CSLF is seeking a communications professional to work with the organisation to create a communications strategy and work plan to achieve this goal.

Background on CSLF

The mission of the CSLF is to facilitate the development and deployment of such technologies via collaborative efforts that address key technical, economic, and environmental obstacles. The CSLF will also promote awareness and champion legal, regulatory, financial, and institutional environments conducive to such technologies.

The CSLF is currently comprised of 23 members, including 22 countries and the European Commission. CSLF member countries represent over 3.5 billion people, or approximately 60% of the world's population.

Membership is open to national governmental entities that are significant producers or users of fossil fuels and that have a commitment to invest resources in research, development and demonstration activities in CO2 capture and storage technologies.

Members of the carbon sequestration stakeholder community are involved with the CSLF and are encouraged to participate and interact with the CSLF.

CSLF Goals

The CSLF Charter, established in 2003, establishes a broad outline for cooperation with the purpose of facilitating development of cost-effective techniques for capture and safe long-term storage of CO2, while making these technologies available internationally.
The CSLF will seek to:

- Identify key obstacles to achieving improved technological capacity;
- Identify potential areas of multilateral collaborations on carbon separation, capture, transport and storage technologies;
- Foster collaborative research, development, and demonstration (RD&D) projects reflecting Members' priorities;
- Identify potential issues relating to the treatment of intellectual property;
- Establish guidelines for the collaborations and reporting of their results;
- Assess regularly the progress of collaborative R&D projects and make recommendations on the direction of such projects;
- Establish and regularly assess an inventory of the potential areas of needed research;

- Organize collaboration with all sectors of the international research community, including industry, academia, government and non-government organizations; the CSLF is also intended to complement ongoing international cooperation in this area;
- Develop strategies to address issues of public perception; and
- Conduct such other activities to advance achievement of the CSLF's purpose as the Members may determine.

Objectives of the communications strategy

- Promote the importance of CCS/CCUS through official communiques and announcements.
- Use high profile events and conferences to provide media opportunities for the CSLF to highlight progress and the need to accelerate the technology
- Facilitate the coordination and focusing of individual member messaging on CCS outside of official CSLF representation
- Use existing CSLF positions on key issues as the basis of communication
- Develop a strategy timetable with a calendar of communications opportunities with a special focus on UN, Government and COP meetings.

Focus of activity

Using existing agreed CSLF messaging, the focus will be on the following areas:

1. Regulation
2. Infrastructure
3. Public engagement
4. Financing
5. Storage

Strategy requirements

It was agreed at the CSLF Policy Group Meeting that the strategy should include:

(1) WHAT is communicated? Key messages – these should be drawn from within the CSLF e.g. using previous communiques and documents already signed off by ministers

(2) WHEN - Events should be prioritised

(3) HOW/WHO - A procedure should be developed setting out how CSLF should engage, WHO and HOW e.g. as individuals, using Ministers etc. Ministers were thought to be very good communicators on behalf of CSLF.

The strategy should also consider how CSLF engages with the media, opportunities to use social media as well as reports and events, and WHO - for example using designated interlocutors to carry messages.

It is important that people and bodies speaking are known and credible (e.g. IEA, DECC, GCCSI have an identity), whereas the “CSLF” brand is currently not known so well. Other points to cover:

- The group should prioritise who to engage with (e.g. UNFCC, IPCC, WEC)
- A procedure should be developed: who should speak
- A process to should be developed with the chairs of each group to agree new messages

Implementation process and approvals

It will be important to confirm the process for the communications consultant to receive overall direction and for media statements/communiques to be agreed. Sufficient time will need to be allowed to do so.

Timings/key dates

A work plan will need to be developed based on key high profile events over the year.

Budget [1]

A budget will need to be allocated to fund the communications professional. A budget is difficult to estimate until the work is agreed. Subject to this an indication of budget would be:

- $30,000 for the work to create the strategy
- $30,000 to support six initiatives once the strategy has been agreed

It is suggested that the work could be done in two phases. The first would be to develop and agree the strategy. The second would be to implement the strategy. This would allow the CSLF to approve the strategy before confirming its implementation.

Note: Budget is indicative and subject to scoping and location of the communications professional. It is assumed that work would not require attendance at meetings but if so travel costs would be additional.

[1] NB: will not be included in approach to market

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Appendix

CSLF Communications Task Force: Recent Key CSLF Messages

These key messages and key actions are drawn from the CSLF Ministerial Communiqué of 8 November 2013 and the CSLF Technology Roadmap. These are high level messages and actions which can be further detailed and defined for particular audiences.

Key Messages

1. CCS is one of the low carbon technology options critical to reduce global GHG emissions from the power and industrial sectors.
2. Significant progress has been made on CCS with 12 large scale projects now operating and a further 10 large scale under construction globally.
3. It is necessary to ensure that conditions are right for all CCS projects currently under construction or in advanced stages of planning to be completed.
4. Any delays in the deployment of CCS would significantly increase the cost of global decarbonisation.
5. CCS R&D, demonstration and deployment must be accelerated.

Key actions needed for CCS deployment

1. Encourage the development of financial frameworks and incentive mechanisms to drive near term demonstration and deployment of CCS and allow CCS technologies to compete fairly with other low carbon technologies.
2. Further develop workable CCS demonstration and deployment strategies in both the power and industrial sectors.
3. Seek and support opportunities for global coordinated efforts on coherent and optimal CCS R&D and demonstrations.
4. Continue to establish permitting frameworks that will ensure the safety and integrity of integrated CCS systems, and eliminate obstacles for their demonstration and deployment.
5. Recognise the need for pre-commercial geological storage validation and encourage cooperation between countries to identify and assess shared geological storage resources and develop plans for their orderly development, including development of associated transportation systems.
6. Strengthen national, regional and international efforts to improve understanding among the public and stakeholders of CCS technology and its importance.
7. Support efforts to grow capacity in CCS and foster appropriate steps in knowledge sharing and technology transfer.
8. Establish international networks, test centres and comprehensive RD&D programmes to verify, qualify and facilitate demonstration of CCS technologies.
9. Gain experience with 1st generation CO2 capture technologies and their integration into power plants and move towards deployment of 2nd generation technologies.
10. Design and implement large-scale national and international CO2 transport networks and infrastructure

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Draft

Carbon Sequestration Leadership Forum

www.cslforum.org

CSLF-T-2014-05
Revised Draft: 22 May 2014
Prepared by CSLF Secretariat

DRAFT

Minutes of the Technical Group Meeting

Seoul, Korea
Tuesday, 25 March 2014

LIST OF ATTENDEES

Chair	Trygve Riis (Norway)

Technical Group Delegates

Australia:	Clinton Foster (*Vice Chair*), Richard Aldous
Brazil:	Ronaldo Amaral
Canada:	Stefan Bachu (*Vice Chair*), Eddy Chui
China:	Jiutian Zhang, Xiaochun Li
European Commission:	Jeroen Schuppers
France:	Didier Bonijoly
Japan:	Ryozo Tanaka
Korea:	Chang-Keun Yi, Chong Kul Ryu
Mexico:	Edgar Santoyo-Castelazo
Netherlands:	Paul Ramsak
Norway:	Jostein Dahl Karlsen, Lars Ingolf Eide
Saudi Arabia:	Ahmed Aleidan, Hamoud Alotaibi
South Africa:	Tony Surridge (*Vice Chair*)
United Kingdom:	Philip Sharman
United States:	Mark Ackiewicz, Geo Richards

Representatives of Allied Organizations

IEA GHG:	Tim Dixon

CSLF Secretariat

Richard Lynch

Invited Speakers

Kiyoung Park, Director General for Energy Efficiency & Climate Change Bureau, Ministry of Trade, Industry and Energy (MOTIE), Korea

Chonghun Han, Chairman of the Steering Committee, Korea Carbon Capture and Storage Association (KCCSA)

Roundtable Participants

Ashok Bhargava, Director, Energy Division, East Asia Department, Asian Development Bank (*Moderator*)

Felipe Flores Pinto, Counselor / Head of Trade Section, Embassy of Brazil (in Korea)

Jiutian Zhang, Deputy Director, ACCA21, Ministry of Science and Technology, China

Edgar Santoyo-Castelazo, Director of Technologic Innovation, SENER, Mexico

Tony Surridge, Senior Manager & Head of the Centre for Carbon Capture and Storage, SANEDI, South Africa

Observers

Asian Development Bank:	Annika Seiler
Canada:	Michael Monea
Korea:	Hwansoo Chang, Seung Phill Choi, Kyungyong Jang, Segyu Jang, Seong Jegarl, Dongkwan Kim, Hocheol Kim, Mihwa Kim
United States:	John Harju, Frank Morton, Katherine Romanak, Edward Steadman

1. Chairman's Welcome and Opening Remarks

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

Trygve Riis

Mr. Riis provided context for the meeting by mentioning that during this meeting the Technical Group would be moving forward on its Action Plan, with the possibility of forming new task forces. However, this would depend in part on appraisals on proposed actions to be presented later in the meeting. Mr. Riis noted that two currently active task forces will be providing updates, as will the Projects Interaction and Review Team (PIRT) which will be describing the process for future updates of the CSLF Technology Roadmap.

In closing, Mr. Riis also mentioned that the current meeting includes a Roundtable on Carbon Capture and Storage (CCS) Technologies and Projects for Emerging Economy Countries, moderated by the Asian Development Bank. And the meeting also includes an informative presentation about the current status of CCS in Korea by the Chairman of the Steering Committee of the Korea Carbon Capture and Storage Association.

2. Host Country Welcome

Kiyoung Park, Director General for Energy Efficiency & Climate Change Bureau at Korea's, Ministry of Trade, Industry and Energy, welcomed the CSLF Technical Group to Seoul and provided a keynote message for the meeting: For Korea and as well as many other countries, CCS can play an important role in greenhouse gas emissions reductions while preserving the option of using coal and other abundant fossil energy resources. Dr. Park stated that the Korean government has set a national master plan in 2010 to pave the way for commercial deployment of advanced CCS technologies by the year of 2020. In line with the plan, Korea has made an investment of US$137 million in carbon capture research, which includes two 10-megawatt post-combustion CO_2 capture pilot plants. Dr. Park also stated that, regarding CO_2 storage, Korea has determined a candidate storage site in the sub-seabed Ulleung Basin of the East Sea, which has the potential to store 5 billion metric tons of CO_2.


Kiyoung Park

Dr. Park closed by stating that Korea is working toward a large-scale CCS demonstration, but in light of the many political and technological barriers to overcome, desires to work with other countries to share best practices to overcome these barriers. For that reason, Korea has a great interest in the CSLF as a platform to share information.

3. Introduction of Delegates

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

4. Adoption of Agenda

The Agenda was adopted without change.

5. Approval of Minutes from Washington Meeting

The Minutes from the November 2013 Technical Group Meeting in Washington were approved without change.

6. Review of Action Items from Washington Meeting

Richard Lynch provided a brief summary of the nine action items resulting from the Washington 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 final review. Dr. Surridge was requested to alert the Secretariat when a final version is available, and the Secretariat will pass this information on to the Technical Group.

Richard Lynch

7. Report from CSLF Secretariat

Richard Lynch gave a brief presentation that summarized ongoing CSLF activities for both the Policy Group and Technical Group. Currently, the Policy Group has two existing task forces, on Financing CCS and on Capacity Building, and has also formed an Exploratory Committee toward creating a forward action plan. The Exploratory Committee has identified five main areas of interest, two of which may involve the Technical Group. The Policy Group is planning to convene twice in 2014. There will be a stand-alone Policy Group meeting tentatively scheduled for June at a yet-to-be-determined location, and the 2014 CSLF Annual Meeting, which will take place sometime in the 4th quarter at a yet-to-be-determined location. The Secretariat was requested to obtain clarification on specific dates and locations for these meetings.

The Technical Group currently has two active task forces, plus the PIRT. Concerning the Technical Group's Action Plan, Mr. Lynch stated that the Secretariat had prepared a status report that is one of the current meeting's room documents. Of the original twelve identified actions from 2011, three are now complete, two are ongoing, and one has been cancelled. Decisions on whether or not to proceed on the remaining six, as well as for the proposed new action on sub-seabed CO_2 geologic storage, would be addressed later in the meeting. Also, one additional action, on review of CO_2 storage efficiency in deep saline aquifers, was added to the Action Plan in 2013 and is currently in progress.

Mr. Lynch also mentioned that he and John Panek (who was not able to attend the current meeting) had written a paper on behalf of the Secretariat for the March 2014 issue of *Petroleum Review*, summarizing the outcomes of 2013 CSLF Ministerial Meeting.

8. CCS in Korea

Chonghun Han

Chonghun Han, Chairman of the Steering Committee for the Korea Carbon Capture and Storage Association (KCCSA), gave a presentation that described the status of CCS in Korea. The Republic of Korea is currently the 8th greatest greenhouse gases emitter, with CO_2 emissions expected to reach more than 800 million tonnes per year by the year 2020 under a "business-as-usual" scenario. To prevent this from happening, the Government of Korea has implemented a National Plan for reducing CO_2 emissions, with a target of 30% reduction from the "business-as-usual" baseline. CCS is expected to play an important role in achieving this goal and, to that end, a Korean National Roadmap for CCS was created in 2009 and Korea's "Nationwide CCS Development Plan" was published in 2010. Power plants are the largest stationary CO_2 emissions sources in Korea, accounting for about one-fourth of the total CO_2 emitted. Because of this, CCS demonstrations are being planned and implement at coal-fueled power plant sites.

Prof. Han reported that there is much R&D activity in progress concerning CO_2 capture. A post-combustion amine-based 0.1 megawatt small pilot unit was operated at the Boryeong Thermal Power Station, in western Korea, between 2010 and 2011; this has now been scaled-up to a 10 megawatt large pilot also at Boryeong. Early test results have shown a greater than 90% CO_2 capture rate with greater than 99% CO_2 purity. Concurrently, another 10 megawatt post-combustion pilot plant is in operation at Hadong Thermal Power Station in southern Korea; this facility utilizes a dry potassium carbonate regenerable sorbent which has an 85% CO_2 capture rate with greater than 95% CO_2 purity. One or both of these processes could have a commercial-scale demonstration by about the year 2018.

Prof. Han stated that work is also progressing on identification and characterization of potential CO_2 storage sites. The largest and most promising is the sub-seabed Ulleung Basin off the eastern coast of Korea, but there are also potential onshore sites being looked at in the southeastern and south-central parts of the country. CO_2 storage will be part of the commercial-scale demonstrations planned for 2018. Prof. Han also mentioned that there is ongoing research in Korea toward CO_2 industrial applications, including CO_2 capture in the steel industry, CO_2 conversion using microalgae, and use of CO_2 as chemical feedstock for a CO_2-epoxide copolymer which has potential as a food packaging material. It is Korea's intention to keep investing in CCS R&D but it needs international collaboration, especially regarding CO_2 storage.

Prof. Han closed his presentation by mentioning that the KCCSA, which came into existence in 2010 as a result of the Nationwide CCS Development Plan, now includes as members all the major players in Korea's power generation, petroleum, and engineering / construction corporations, and it's bimonthly newsletter has a distribution list of about 62,000 recipients. KCCSA is an active participant in international CCS networks and is involved in development of a regulatory / incentive system that is expected to encourage CCS commercialization in Korea.

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


Tim Dixon

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. A major activity of the IEA GHG this year is sponsorship of the GHGT-12 conference in the United States on 5-9 October (in Austin, Texas). This biennial event is the largest and most comprehensive conference related to CCS.

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 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). Mr. Dixon stated that new ideas for future studies are welcome, and that the next deadline for proposal outlines is on 19 June 2014.

10. Update from the Global CCS Institute

Clinton Foster gave a brief presentation on behalf of the GCCSI, whose representative was not able to attend the meeting. The mission of the GCCSI is to accelerate the development, demonstration and deployment of CCS globally. The methodology for doing this is through knowledge sharing, fact-based advice and advocacy, and working to create favorable conditions for implementation of CCS. The GCCSI has had more than 600 publications on a variety of topics related to CCS including its flagship report, "The Global Status of CCS", which was launched in October 2013 and updated in February 2014. The GCCSI also collaborates with several organizations, including the CSLF, and the focus of the collaboration with the CSLF is on capacity building and knowledge sharing.

Dr. Foster also stated that the GCCSI recently created the "**decarboni.se**" website, which presents an opportunity for CSLF outcomes to gained wider visibility. This is intended to be a knowledge hub for CCS and other low carbon technologies, providing platforms for organizations and corporations to build knowledge-sharing mini-websites within the knowledge hub. The CSLF is one of more than 400 such organizations.

Trygve Riis, speaking for the Technical Group, expressed appreciation for the GCCSI's continuing involvement in CSLF activities.

11. Report from the CSLF Projects Interaction and Review Team (PIRT) and Update on the CSLF Technology Roadmap

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 new Active members were added to the PIRT: Jiutian Zhang (China), Edgar Santoyo-Castelazo (Mexico), and Paul Ramsak (Netherlands).
- The PIRT will continue its collaborations with other CCS organizations in the area of knowledge sharing. To that end, the GCCSI's "**decarboni.se**" website will be linked from the CSLF website.
- The PIRT will gather information on the eight "Identified Technology Needs" that were described in the 2013 CSLF Technology Roadmap (TRM). The CSLF Secretariat will develop templates for this purpose which will be sent to representatives of other CCS organizations.
- New working groups will be formed within the PIRT to examine information received concerning the eight TRM needs areas:

  Area #1: CO_2 Capture Technologies in Power Generation (*Norway*)

  Area #2: CO_2 Capture in Industrial Sector (*South Africa* and *United Kingdom*)

  Area #3: CO_2 Transport (*Australia*)

  Area #4: Large-Scale CO_2 Storage (*Japan* and *France*)

  Area #5a: Monitoring (*United States* and *France*)

  Area #5b: Mitigation / Remediation (*European Commission*)

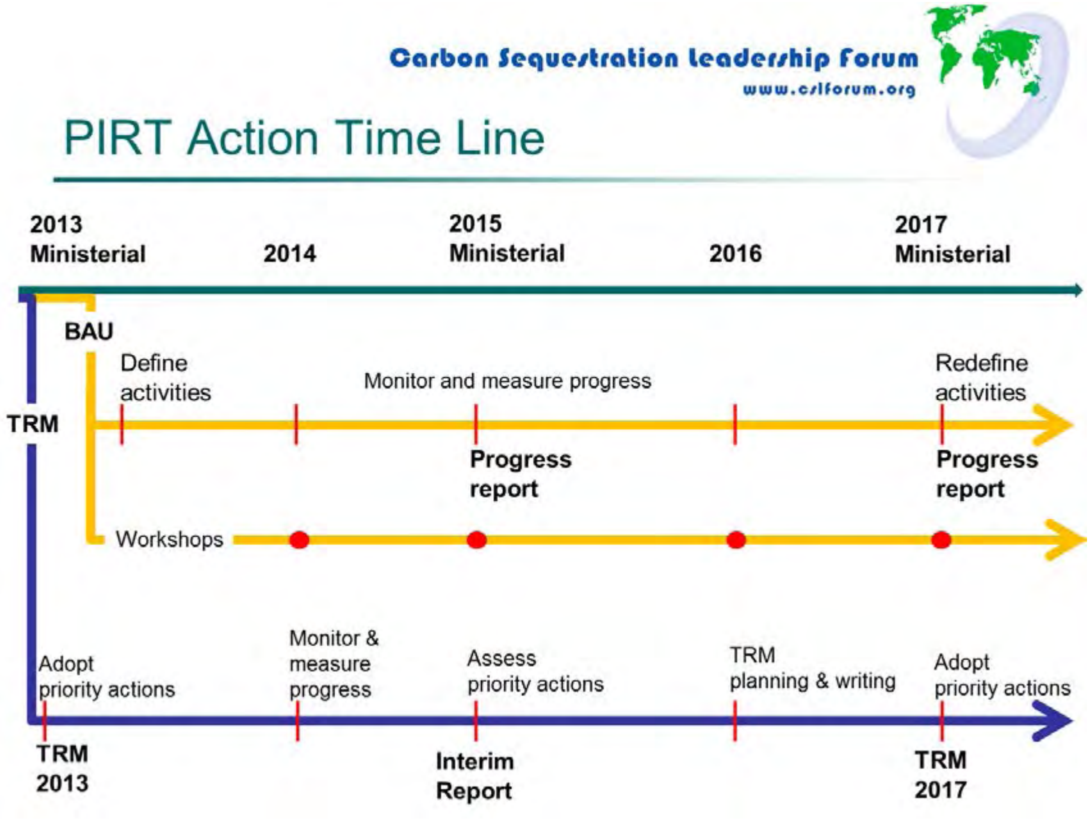
Area #6: Understanding the Storage Reservoirs (*United Kingdom* – to be confirmed)

Area #7: Infrastructure (*United Kingdom* – to be confirmed)

Area #8a: CO_2 Utilization, non-Enhanced Oil Recovery [EOR] (*France* – to be confirmed)

Area #8b: CO_2 Utilization, EOR (*Saudi Arabia*)

- There will not be a major rewrite of the TRM until 2017 (see chart). Results of the information gathering survey would be used to develop a 2014 Progress Report Addendum for the 2013 TRM and potentially a 2015 Interim Report for the next CSLF Ministerial Meeting.



Ensuing discussion focused on the TRM and associated information gathering activities. Didier Bonijoly noted that even though France is shown as lead or co-lead for several of the needs areas, it may not be possible, due to the amount of work involved, to actively participate in all of them. Philip Sharman noted that while this information survey would pertain more toward year 2020 CCS goals, the longer-term objectives for 2030 and 2050 should also be taken into account – fundamental research on advanced capture processes and next generation demonstration projects will be needed as time goes on, and these should be part of any projected timeline. Stefan Bachu agreed, stating that by the next Ministerial Meeting, it would likely not be enough time for any new advances to make it to demonstration by the year 2020. Because of this, Dr. Bachu suggested that for the next major TRM rewrite, the Technical Group should move its focus to beyond the year 2020. Lars Ingolf Eide also agreed, and mentioned that this change in focus outward from 2020 should be part of any joint activities the Technical Group has with the Policy Group, since the Policy Group is now discussing 2nd and 3rd generation technologies as it develops its own action plan. However, Trygve Riis commented that even though lengthening the focus of the TRM to 2030 makes sense, shorter-term recommendations are still important as these would be of more immediate interest to the CSLF Ministers when they next meet.

12. Report from Review of CO_2 Storage Efficiency in Deep Saline Aquifers Task Force

Stefan Bachu

The Task Force Chair, Stefan Bachu, gave a brief update on the task force and its timeline. Dr. Bachu reported that this task force was established at the previous CSLF Technical Group Meeting, in November 2013, and has the mandate to critically review, compile and report on relevant literature published since the 2007 final report by the CSLF Task Force for Review and Identification of Standards for CO_2 Storage Capacity Estimation. The new task force has so far identified and collected more than 70 published papers and reports, as well as several that are yet to be published and presented. Outcomes from the task force's activities will lead to the refinement of values for storage capacity coefficients for deep saline aquifers, and as a result, update of known CO_2 storage capacities for these reservoirs. A draft of the task force's final report is expected to be complete in time for the 2014 CSLF Annual Meeting with a final version ready in time for the 2015 Technical Group Meeting.

During the ensuing discussion, Jostein Dahl Karlsen inquired if actual field information from ongoing projects would be reviewed in addition to published literature. Dr. Bachu responded that this would probably not be possible because these projects will not have reached the end of their injection stages in time for the task force's report, and also because some if not most of this field information would likely be proprietary. Ahmed Aleidan and Ryozo Tanaka both asked what kind of methodologies were used to develop values for storage coefficients, and Dr. Bachu clarified that these were determined based on numerical simulations. Richard Lynch inquired if outcomes from the task force would invalidate information contained in CO_2 storage atlases that have been published. Dr. Bachu replied that, at a minimum, any storage atlases published prior to 2007 would be obsolete because of the evolving methodology for determining these storage estimates.

13. 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 report on the activities of this task force. The task force mandate was to perform initial identification and review of standards for storage and monitoring of injected CO_2. In the two years of its existence, the task force has completed annual reports that compiled listings of Best Practices Manuals (BPMs) that have been issued by various projects and organizations. Mr. Eide stated that the task force had intended to move onto Phase 2 activities, which would have had a focus of outlining/designing a web-based solution that can be used for future annual updates. However, sufficient resources to continue this activity have not been forthcoming. Also, there are indications that other organizations such as the European Commission's CO_2 GeoNet Project and the ISO TC265 committee on CCS may be planning similar activities. For these reasons, Mr. Eide recommended that the task force be discontinued. Mr. Eide also suggested that the task force's compilation of BPMs be translated to a web-based product at the CSLF website and there was consensus for the Secretariat to make this transition. Mr. Eide was requested to inquire with the CO_2 GeoNet Project to determine what reports and outreach activities are planned concerning BPMs.

After brief discussion, there was consensus that this task force has concluded its work.

14. Report on Barriers and Technical Needs for Sub-Seabed Storage of CO_2

Mark Ackiewicz

Mark Ackiewicz gave a short presentation that proposed creation of a new task force on offshore CO_2 storage. The November 2013 Technical Group Meeting in Washington had included a presentation on offshore carbon storage, but there was no consensus at that time for a new task force in this area. Subsequently, the United States volunteered to lead such a task force. Mr. Ackiewicz stated that offshore sub-seabed geologic storage can create additional CO_2 storage opportunities and may have several advantages, including avoidance of issues associated with heavily populated onshore areas and utilization of other subsurface resources.

Mr. Ackiewicz stated that a new task force in this area would provide a current assessment on the status of the global sub-seabed storage potential, including potential for offshore EOR. The task force would also identify technical barriers and challenges to sub-seabed CO_2 storage (such as site characterization, monitoring, and CO_2 transport) as well as R&D opportunities. Identification of any existing projects characterization activities of this nature would also be part of the task force's activities, and the task force would also identify potential opportunities for global collaboration. Mr. Ackiewicz stated that the proposed new task force would be able to make a progress report at the next CSLF Annual Meeting, and would plan for a draft of its final report to be completed by the end of 2014. A final version of the report would be ready in time for the 2015 Technical Group Meeting.

Ensuing discussion resulted in consensus to create the new task force. Philip Sharman, Ryozo Tanaka, Lars Ingolf Eide, and Tim Dixon all volunteered to participate, though Mr. Eide stated that since Statoil in Norway had been doing sub-seabed injection of CO_2 for many years, there should be an effort to have Statoil representation in the task force. Clinton Foster suggested that the name of the new task force not include the word 'barriers' due to its negative connotation. Mr. Ackiewicz agreed, and the new task force will henceforward be known as the Offshore CO_2 Storage Task Force.

15. Analysis of IEA GHG Report on Interaction of CO_2 Storage with Subsurface Resources

Didier Bonijoly

Didier Bonijoly gave a short presentation that appraised the state of knowledge (based on his review of the IEA GHG Report 2013-08) concerning the proposed Technical Group Action Plan item on "Competition of CCS with Other Resources" in order to determine if the Technical Group should form a new task force in this area. Dr. Bonijoly stated that there were many potential subsurface resources considered in the IEA GHG report, including conventional oil and gas, shale gas and oil, coal, gas hydrates, natural gas storage, geothermal energy, groundwater, mineral deposits, and even nuclear waste repositories. The findings from this analysis were that risk assessments would probably be necessary concerning some of these subsurface resources but overall, the IEA GHG report and associated documentation were complete and pertinent, and there was no particular need for complementary work from the CSLF Technical Group.

After brief discussion there was consensus that the Technical Group will not form a new task force on this topic.

16. Appraisal of Proposed Technical Group Actions concerning CCS with Industrial Emissions Sources


Tony Surridge

Tony Surridge gave a short presentation concerning the proposed Technical Group Action Plan item on "CCS with Industrial Emissions Sources". Dr. Surridge's presentation described results of a South African case study of carbon emitters in and near the city of Durban, which is relatively close to a potential offshore sub-seabed storage site, and like many industrialized areas, is host to a large number of relatively small carbon emitters and a small number of large emitters. The large emitters are, individually, potential CCS opportunities, and it may also be possible to "pool" CO_2 streams from some of the smaller emitters such that the aggregate stream is of sufficient scale to warrant interest for CCS. There are many factors – policy, economic, and technical – that would enter into any decision on whether to proceed toward implementation of CCS projects.

Dr. Surridge's presentation did not make a recommendation on whether or not there should be a new Technical Group task force to further investigate this area, but ensuing discussion led to the conclusion that there may be some worth in further pursuing this topic. Lars Ingolf Eide mentioned that there has been a four-year project in Norway on industrial CO_2 emissions, which will wrap up with a workshop in June. Philip Sharman stated that there has been an ongoing study in the United Kingdom about CCS in industrial sectors, with a report due later in 2014. In the end, there was agreement to defer a decision on forming a new task force until the next Technical Group meeting when a final determination would be made, so that results from the Norway workshop and the United Kingdom report can first be reviewed and considered.

Dr. Surridge mentioned that there will also be a brief "framework" report from South Africa on this topic, but it will first need to be reviewed before it can be released for wider distribution. The United Kingdom, United States, Norway, and the IEA GHG all volunteered to review the report, and Dr. Surridge agreed to send the final report to the Secretariat for posting at the CSLF website.

17. Appraisal of Proposed Technical Group Actions concerning Energy Penalty Reduction and Carbon Neutral / Carbon Negative CCS

Philip Sharman

Philip Sharman provided short appraisals on whether or not the Technical Group should form new task forces concerning the proposed Technical Group Action Plan items on "Energy Penalty Reduction" and "Carbon Neutral / Carbon Negative CCS". Concerning "Energy Penalty Reduction", Mr. Sharman stated that results from the United Kingdom's CCS Cost Reduction Task Force has been a useful stepping-off point for broader analysis, and that front-end engineering design (FEED) studies have been recently launched on the United Kingdom's commercial-scale Peterhead and White Rose projects. Outcomes from these studies would be extremely pertinent, but would not be available in time for use by a new Technical Group task force in this area. Mr. Sharman also stated that the United Kingdom is in the process of forming several new fora and networks, including one on knowledge transfer, which would most likely be addressing energy penalty reduction aspects for CCS. For these reasons, Mr. Sharman suggested that the Technical Group defer any decision on forming a new task force until the next Technical Group meeting, at which enough new information may be available such that a final determination can be made. There was consensus to accept this recommendation.

Concerning "Carbon Neutral / Carbon Negative CCS", Mr. Sharman stated that the European Commission's Zero Emissions Platform (ZEP) task force has already produced a report on this topic and that there were also other activities underway, including three IEA GHG studies. Mr. Sharman stated that these ongoing activities are providing very good coverage in this area and there did not seem to be any reason for the CSLF to form a new task force that would essentially duplicate some of these investigations. After brief discussion, there was consensus that the Technical Group will not form a new task force on this topic.

18. Appraisal of Proposed Technical Group Actions concerning Lifecycle Assessment and Environmental Footprint of CCS

Lars Ingolf Eide provided his appraisal concerning the proposed Technical Group Action Plan item on "Lifecycle Assessment and Environmental Footprint of CCS", and recommended that the Technical Group should not form a new task force on this topic. Mr. Eide stated that there are some definite resource considerations if a new task force were to be formed, as it is a big undertaking to evaluate lifecycle assessments. Also, any new task force might duplicate activities of the ISO TC265 committee on CCS, which has this topic on its agenda. Mr. Eide suggested that, instead, it might be better if the IEA GHG played a role in this area. Tim Dixon replied that the IEA GHG would certainly be interested in entertaining a proposal for a study on this topic, and reminded that the deadline for proposal outlines is mid-June, as he had previously described. Proposals received by then would be evaluated at the IEA GHG's Executive Committee meeting in October.

After brief discussion, there was agreement that Mr. Eide and Mr. Dixon would jointly develop a proposal for a future IEA GHG study on lifecycle assessments.

19. Appraisal of Proposed Technical Group Actions concerning CO_2 Compression and Transport

Ryozo Tanaka

Ryozo Tanaka provided his appraisal concerning the proposed Technical Group Action Plan item on "CO_2 Compression and Transport", which concluded that while there are no significant challenges to be addressed concerning CO_2 compression, Technical Group activities concerning CO_2 transport might be worthwhile. However, Mr. Tanaka stated that Japan would like to decline the request to be the lead for a potential new task force on CO_2 transport because Japan's Ministry of Economy, Trade and Industry (METI) believes that Japan should put a higher priority on capture and storage, in particular offshore storage, than on CO_2 transport. Instead, Mr. Tanaka proposed that this Action Plan item become a part of the new Offshore CO_2 Storage Task Force. There was consensus for this proposal, and Mr. Tanaka volunteered to contribute to the new task force.

20. Roundtable Event: CCS Technologies and Projects for Emerging Economies

L-R: Tony Surridge, Edgar Santoyo-Castelazo, Felipe Flores Pinto, Jiutian Zhang, Ashok Bhargava

Richard Lynch introduced the Roundtable by stating that this event was intended to provide a depiction of how CCS would work best in emerging economy countries – what technologies would be of interest and what kinds of projects would make sense. Mr. Lynch then introduced the moderator, Ashok Bhargava of the Asian Development Bank (ADB), and the four panelists: Felipe Flores Pinto (representing Brazil), Jiutian Zhang (representing China), Edgar Santoyo-Castelazo (representing Mexico), and Tony Surridge (representing South Africa).

Mr. Bhargava provided a prolog to the Roundtable by stating that the ADB's Energy Division oversees a CCS dedicated fund of about US$70 million, which supports capacity building, strategic analyses, project preparation activities, and financing of pilot projects, with emphasis on China and Indonesia. In 2014 the ADB expects to assist in the financing of two pilot projects. Each of the four panelists then provided a short scene-setting description that described CCS intentions for their countries. Mr. Pinto stated that fossil energy is not a major player in Brazil's energy mix, and the main interest was in developing offshore oil and gas reserves without venting CO_2 associated with this oil and gas. Dr. Zhang stated that China's growing need for sustainable sources of energy has led it to look for integrated solutions that solve more than just the issues related to CO_2, and that CO_2 utilization is also of interest. Dr. Santoyo-Castelazo stated that Mexico is a fast-industrializing country with an economy heavily dependent on fossil fuels, and that a new regulatory framework for climate change now being developed has created interest toward integrated CCS solutions, including CCS on gas-fired power plants. Dr. Surridge stated that South Africa's main focus has been on CO_2 storage with a pilot project in the planning stages, and that a proposed new carbon tax in South Africa would provide a strong impetus for CCS projects to happen. Ensuing discussion led to the following takeaways:

- CCS, as part of a suite of low carbon options, is becoming a national priority area for emerging economy countries. However, in some cases, lack of regulatory frameworks and other policy-related issues are holding back CCS.
- Resource allocation will always be an issue for implementing CCS in emerging economy countries, and funding is usually a zero-sum situation. Resources are limited, and the most urgent national needs get addressed first.
- Even though there are many similarities in the needs of emerging economy countries, each country has a specific set of circumstances in terms of national priorities, and this results in different strategies for implementing various aspects of CCS.
- One of the biggest challenges will be locating and characterizing CO_2 storage sites. While CO_2 capture and transport technologies can be brought in from the outside, CO_2 storage is always a local issue.
- Capacity building activities are essential to create in-country expertise for CCS in the developing world. The CSLF Capacity Building Program has been very beneficial, but much more is needed.

21. Discussion of the Need for New Technical Group Task Forces

Trygve Riis inquired if there were ideas for other possible additions to the Technical Group Action Plan. Jostein Dahl Karlsen offered that the Technical Group should embrace the concept of "policy relevance" (making Technical Group activities relevant to the Policy Group). For example, onshore CCS in Europe currently has considerable public acceptance issues to overcome, and as a result there may be an opportunity for the Technical Group to fashion "integrity of CCS" information for the layman which would capitalize on the real-world experiences of large-scale injection projects. Philip Sharman suggested that there may be some worth, in the future, for the Technical Group examining learnings from FEED studies, for instance a comparison of differences and similarities. Clinton Foster suggested that modeling techniques could be investigated, though there could not be appearance of an endorsement for any model.

To build on Mr. Karlsen's idea, Stefan Bachu stated that public outreach and communications was already part of the Policy Group's agenda, and this was an area where the Technical Group could provide tools for assisting the Policy Group. Ensuing discussion led to a proposal for creation of a new exploratory committee to review available information on monitoring technologies at existing projects, which would support the Policy Group's public outreach activities. However, there was no immediate consensus to move forward in this area. Concerning this and the other suggestions, Mr. Riis stated that these will be discussed and firmed up during future Technical Group Executive Committee teleconferences.

22. Possibilities for Collaboration with the CSLF Policy Group

Trygve Riis informed the Technical Group about ongoing Policy Group activities for developing its own Action Plan. A Policy Group Exploratory Committee was formed at the November 2013 CSLF Ministerial Meeting and has 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. Mr. Riis state that two of these topics are relevant to the Technical Group: supporting the development of 2nd and 3rd generation CCS technologies; and transitioning from CO_2-EOR to CCS. The latter topic was incorporated at the suggestion of the Technical Group. There was discussion on what the Technical Group's role might be for each of these items, but in the end there was the realization that these are still only proposals at this stage so no Technical Group activity is yet necessary. The upcoming Policy Group Meeting is expected to clarify the necessity for any Technical Group involvement.

23. New Business

There was no new business.

24. Review of Consensuses Reached and Action Items

Consensus was reached on the following items:

- The Reviewing Best Practices and Standards for Geologic Storage and Monitoring of CO_2 Task Force has concluded its work.
- A new Offshore CO_2 Storage Task Force is created and will be led by the United States.
- The Technical Group will not form a task force to address the Action Plan item on "Competition of CCS with Other Resources".
- The Technical Group will not form a task force to address the Action Plan item on "Carbon Neutral / Carbon Negative CCS".
- The Technical Group will not form a task force to address the Action Plan item on "Lifecycle Assessment and Environmental Footprint".
- The Technical Group will not form a task force to address the Action Plan item on "CO_2 Compression and Transport", instead incorporating this area into the new task force on "Offshore Sub-Seabed Storage of CO_2".
- The Technical Group will defer decisions on forming new task forces for the Action Plan items on "CCS with the Industrial Emissions Sources" and "Energy Penalty Reduction", and make final determinations on whether or not to address these items at the next Technical Group meeting.

Action items from the meeting are as follows:

Item	Lead	Action
1	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.
2	CSLF Secretariat	Obtain clarification on the specific dates and locations for the June 2014 Policy Group meeting and the 2014 CSLF Annual meeting.
3	Norway	Inquire with the European Commission's CO_2 GeoNet Project to determine what reports and outreach activities are planned concerning BPMs.
4	CSLF Secretariat	Create a new page at the CSLF website for compilation of BPMs and other results from the Reviewing Best Practices and Standards for Geologic Storage and Monitoring of CO_2 Task Force.
5	United Kingdom, United States, Norway, IEA GHG	Review South African "framework" report on industrial sector CCS.
6	South Africa	Send finalized "framework" report to Secretariat for posting at CSLF website once it is ready.
7	Norway and IEA GHG	Develop a proposal for a future IEA GHG study on lifecycle assessments.
8	CSLF Secretariat	Update the Technical Group Action Plan.

25. Closing Remarks / Adjourn

Trygve Riis expressed appreciation to the host country for bringing the Technical Group to Korea, and to Chong Kul Ryu in particular for all the work and preparation he did to make the meeting happen. Mr. 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

CSLF-T-2014-07
29 September 2014

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TECHNICAL GROUP

Progress Report on the 2013 CSLF Technology Roadmap

Background

At the November 2013 CSLF Ministerial Meeting in Washington, the Technical Group launched the 2013 CSLF Technology Roadmap (TRM). At the March 2014 CSLF Technical Group Meeting in Seoul, it was decided that the Technical Group would produce a short update on the 2013 TRM in lieu of creating a new 2014 TRM.

To that end, this paper, prepared by the CSLF Secretariat, is a **draft interim progress report** on the 2013 TRM, based on information received as of September 29, 2014. An update, incorporating information received after September 29, will be prepared for the June 2015 CSLF Technical Group Meeting in Regina.

Action Requested

The Technical Group is requested to review the draft interim TRM Progress Report.

Draft

Carbon Sequestration Leadership Forum
www.cslforum.org

CSLF-T-2014-07
29 September 2014

Progress Report on the 2013 CSLF Technology Roadmap

Introduction

The 2013 CSLF Technology Roadmap (TRM) was launched at the 5th CSLF Ministerial Meeting in November 2013 as the latest in a series of TRM documents that date back to 2004. The main objective of the 2013 TRM was to recommend to governments the technology priorities for successful implementation of carbon capture and storage (CCS) in the power and industrial sectors. In particular, the 2013 TRM was intended to answer 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 2013 TRM contained several key recommendations for advancing carbon capture and storage (CCS) technologies toward the year 2020 and beyond:

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.
- 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-enhanced oil recovery (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 1st generation technologies costs.

The 2013 TRM also identified ten different technology needs areas that are vital for successful commercial implementation of large-scale CCS projects:

a) CO_2 capture in power generation
b) CO_2 capture in the industrial sector
c) CO_2 transport
d) Large-scale CO_2 storage
e) Monitoring stored CO_2
f) Mitigation / remediation procedures
g) Understanding storage reservoirs
h) Infrastructure and the integrated CCS chain (capture to storage)
i) CO_2 utilization, non-EOR
j) CO_2 utilization, EOR

To that end, a template was developed for tracking progress and gathering pertinent information on the perceived status of each of the ten technology needs areas. (*Note: the template is appended to this Progress Report.*) Information gathered by the template will assist the Technical Group to chart progress in both application and adaption of 1st generation technologies that are now being used in commercial or demonstration-scale CCS projects; and also 2nd and 3rd generation technologies that are being tested in pilot-scale CCS projects (i.e., >1 MW and/or >1,000 tonnes of CO_2 injected per year). Also, although the 2013 TRM covers decadal timeframes towards the years 2020, 2030, and 2050, this survey is only concerned with progress towards the year 2020.

This template was sent to organizations in CSLF member countries that are working to develop, improve, demonstrate, or implement technologies relevant to CCS. Representatives of these organizations were requested to provide their evidence-based opinions, for each of the ten technology needs areas, on whether progress in these areas was occurring either very slowly, or at moderate pace, or fast moving. They were also asked to indicate if there were economic, policy, and/or technological drivers that are affecting the relative amount of progress. Finally, they were asked to provide this information in two different modes: progress within their respective countries, and global trends.

Preliminary Results of the Survey

As of September 29, a total of 12 completed templates have been received. This is not nearly enough to definitively describe the global status of CCS technologies, but there are some trends that are evident.

Global Trends

Overall, for 1st generation technologies, *none* of the ten technology needs areas were in general perceived as progress being "fast moving". There was one area ("CO_2 utilization, non-EOR") where progress was nearly unanimously perceived as "very slow", and two other areas ("CO_2 capture in power generation" and "CO_2 utilization, EOR") where progress was perceived as "moderate". All the other technology needs areas were perceived as a mixed opinion, with "very slow" and "moderate" having comparable numbers of responses. There was also a geographic bias in the results, with North American responders, in general, having a more pessimistic outlook than their European and Asian counterparts. For 2nd and 3rd generation technologies the results were identical, except that there was much more perceived uncertainty – the total number of "no opinion" responses was triple that received for 1st generation technologies.

There was also no clear-cut singling-out of specific barriers (or drivers) which are affecting the relative amount of progress in development of CCS technologies. All types of barriers – economic, policy, and technology – were perceived to exist for most of the technology needs areas, but there were a few exceptions: for three of the areas ("CO_2 transport", "Large-scale CO_2 storage", and Infrastructure and the integrated CCS chain") there were no perceived technology-related barriers. *All* areas were perceived to have economic barriers and policy-related barriers.

Composite results of the survey are shown in Table 1. The takeaway from these results is that the 2013 TRM is still reasonably accurate in its description and portrayal of the status and barriers/drivers for development and deployment of CCS technologies. There is still a need for progress in all of the ten technology needs areas, but some much more than others.

Table 1: Composite Results of Survey (Global Trends)

Technology Needs Area	1st Generation Technologies – Progress toward 2020	2nd – 3rd Gen. Technologies – Progress toward 2020	What kinds of barriers exist?		
			Economic	Policy	Technology
a) CO_2 Capture in Power Generation	Moderate	Very Slowly to Moderate	Yes	Yes	Yes
b) CO_2 Capture in Industrial Sector	Very Slowly to Moderate	Very Slowly	Yes	Yes	Yes
c) CO_2 Transport	Very Slowly to Moderate	Very Slowly to Moderate	Yes	Yes	
d) Large-Scale CO_2 Storage	Very Slowly to Moderate	Very Slowly to Moderate	Yes	Yes	
e) Monitoring Stored CO_2	Moderate	Very Slowly to Moderate	Yes	Yes	Yes
f) Mitigation / Remediation Procedures	Moderate	Very Slowly to Moderate	Yes	Yes	Yes
g) Understanding Storage Reservoirs	Very Slowly to Moderate	Very Slowly to Moderate	Yes	Yes	Yes
h) Infrastructure and the Integrated CCS Chain (capture to storage)	Very Slowly	Very Slowly	Yes	Yes	
i) CO_2 Utilization, non-EOR	Very Slowly	Very Slowly	Yes	Yes	Yes
j) CO_2 Utilization, EOR	Moderate	Very Slowly	Yes	Yes	Yes

Individual Country Trends

The 12 responses received represented seven different countries: four from Norway, three from the United States, and one each from Canada, China, the European Commission (specific to Spain), Japan, and Saudi Arabia. Perceived progress for each of these countries is shown in Tables 2-8 (note: Canada responded only for the "CO_2 Utilization, EOR" technology needs area, and the results for Norway and the United States are composites of the individual responses).

These country-specific results illustrate that issues surrounding CCS are viewed in different ways in different parts of the world. In China, for example, there are perceived policy-related barriers for all ten of the technology needs areas, while the European Commission sees policy-related barriers in only a few areas. There were also a wide range of responses in the perceived status for the ten technology needs areas. An example of this are the responses for 1st Generation Technologies for "CO_2 Capture in the Industrial Sector", which ranged from "Fast Moving (China) to "Very Slowly" (European Commission and Saudi Arabia).

The takeaway from these results is that CCS is not a "one size fits all" collection of technologies. The 2013 TRM is a very good document for recommending technology options for a generalized global setting, but there is also a great need for individualized country-specific technology roadmaps.

Table 2: Results for Canada

Technology Needs Area	**1st Generation Technologies – Progress toward 2020**	**2nd – 3rd Gen. Technologies – Progress toward 2020**	**What kinds of barriers exist?**		
			Economic	**Policy**	**Technology**
a) CO_2 Capture in Power Generation					
b) CO_2 Capture in Industrial Sector					
c) CO_2 Transport					
d) Large-Scale CO_2 Storage					
e) Monitoring Stored CO_2					
f) Mitigation / Remediation Procedures					
g) Understanding Storage Reservoirs					
h) Infrastructure and the Integrated CCS Chain (capture to storage)					
i) CO_2 Utilization, non-EOR					
j) CO_2 Utilization, EOR	Moderate	Very Slowly	Yes	Yes	Yes

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Table 3: Results for China

Technology Needs Area	**1st Generation Technologies – Progress toward 2020**	**2nd – 3rd Gen. Technologies – Progress toward 2020**	**What kinds of barriers exist?**		
			Economic	**Policy**	**Technology**
a) CO_2 Capture in Power Generation	Moderate	Moderate	Yes	Yes	
b) CO_2 Capture in Industrial Sector	Fast Moving	(*No opinion*)		Yes	
c) CO_2 Transport	Very Slowly	(*No opinion*)		Yes	
d) Large-Scale CO_2 Storage	Moderate	Moderate		Yes	
e) Monitoring Stored CO_2	Very Slowly	Very Slowly		Yes	Yes
f) Mitigation / Remediation Procedures	Very Slowly	Very Slowly		Yes	
g) Understanding Storage Reservoirs	Moderate	(*No opinion*)		Yes	Yes
h) Infrastructure and the Integrated CCS Chain (capture to storage)	Moderate	Very Slowly	Yes	Yes	
i) CO_2 Utilization, non-EOR	Fast Moving	Moderate	Yes	Yes	
j) CO_2 Utilization, EOR	Moderate	Very Slowly		Yes	Yes

Table 4: Results for European Commission / Spain

Technology Needs Area	**1st Generation Technologies – Progress toward 2020**	**2nd – 3rd Gen. Technologies – Progress toward 2020**	**What kinds of barriers exist?**		
			Economic	**Policy**	**Technology**
a) CO_2 Capture in Power Generation	Very Slowly	Moderate	Yes		Yes
b) CO_2 Capture in Industrial Sector	Very Slowly	Very Slowly	Yes		Yes
c) CO_2 Transport	Very Slowly	Very Slowly	Yes		
d) Large-Scale CO_2 Storage	Moderate	Very Slowly	Yes	Yes	
e) Monitoring Stored CO_2	Moderate	Very Slowly	Yes	Yes	
f) Mitigation / Remediation Procedures	Very Slowly	Very Slowly	Yes		
g) Understanding Storage Reservoirs	Moderate	Moderate	Yes		
h) Infrastructure and the Integrated CCS Chain (capture to storage)	Very Slowly	Very Slowly	Yes	Yes	
i) CO_2 Utilization, non-EOR	Very Slowly	Very Slowly	Yes		Yes
j) CO_2 Utilization, EOR	(*No opinion*)	(*No opinion*)			

Table 5: Results for Japan

Technology Needs Area	1st Generation Technologies – Progress toward 2020	2nd – 3rd Gen. Technologies – Progress toward 2020	What kinds of barriers exist?		
			Economic	Policy	Technology
a) CO_2 Capture in Power Generation	Moderate	Very Slowly	Yes	Yes	
b) CO_2 Capture in Industrial Sector	Moderate	Moderate	Yes	Yes	
c) CO_2 Transport	Very Slowly	Moderate	Yes	Yes	
d) Large-Scale CO_2 Storage	Moderate	Very Slowly		Yes	
e) Monitoring Stored CO_2	Moderate	Moderate		Yes	
f) Mitigation / Remediation Procedures	Very Slowly	(*No opinion*)		Yes	
g) Understanding Storage Reservoirs	Moderate	(*No opinion*)		Yes	Yes
h) Infrastructure and the Integrated CCS Chain (capture to storage)	Very Slowly	(*No opinion*)		Yes	
i) CO_2 Utilization, non-EOR	Very Slowly	(*No opinion*)	Yes		
j) CO_2 Utilization, EOR	Very Slowly	(*No opinion*)			

Table 6: Results for Saudi Arabia

Technology Needs Area	1st Generation Technologies – Progress toward 2020	2nd – 3rd Gen. Technologies – Progress toward 2020	What kinds of barriers exist?		
			Economic	Policy	Technology
a) CO_2 Capture in Power Generation	Very Slowly	Very Slowly	Yes		
b) CO_2 Capture in Industrial Sector	Very Slowly	Very Slowly	Yes		
c) CO_2 Transport	Moderate	Very Slowly	Yes		
d) Large-Scale CO_2 Storage	Very Slowly	Very Slowly		Yes	
e) Monitoring Stored CO_2	Moderate	Fast Moving		Yes	Yes
f) Mitigation / Remediation Procedures	Very Slowly	Moderate	Yes	Yes	
g) Understanding Storage Reservoirs	Moderate	Moderate	Yes	Yes	
h) Infrastructure and the Integrated CCS Chain (capture to storage)	Very Slowly	Very Slowly	Yes		
i) CO_2 Utilization, non-EOR	Moderate	Very Slowly	Yes		Yes
j) CO_2 Utilization, EOR	Moderate	Moderate	Yes	Yes	Yes

Table 7: Composite Results for Norway

Technology Needs Area	1st Generation Technologies – Progress toward 2020	2nd – 3rd Gen. Technologies – Progress toward 2020	What kinds of barriers exist?		
			Economic	Policy	Technology
a) CO_2 Capture in Power Generation	Very Slowly to Moderate	Very Slowly	Yes	Yes	
b) CO_2 Capture in Industrial Sector	Moderate to Fast Moving	Very Slowly to Moderate	Yes	Yes	Yes
c) CO_2 Transport	Very Slowly to Moderate	Very Slowly to Moderate	Yes	Yes	
d) Large-Scale CO_2 Storage	Very Slowly to Moderate	Very Slowly to Moderate	Yes	Yes	
e) Monitoring Stored CO_2	Moderate	Very Slowly	Yes	Yes	Yes
f) Mitigation / Remediation Procedures	Very Slowly	Very Slowly	Yes	Yes	Yes
g) Understanding Storage Reservoirs	Moderate	Moderate			Yes
h) Infrastructure and the Integrated CCS Chain (capture to storage)	Very Slowly to Moderate	Very Slowly	Yes	Yes	
i) CO_2 Utilization, non-EOR	Very Slowly	Very Slowly	Yes	Yes	Yes
j) CO_2 Utilization, EOR	Very Slowly to Moderate	Very Slowly	Yes	Yes	Yes

Table 8: Composite Results for United States

Technology Needs Area	1st Generation Technologies – Progress toward 2020	2nd – 3rd Gen. Technologies – Progress toward 2020	What kinds of barriers exist?		
			Economic	Policy	Technology
a) CO_2 Capture in Power Generation	Moderate	Moderate	Yes	Yes	Yes
b) CO_2 Capture in Industrial Sector	Moderate	(*No opinion*)			
c) CO_2 Transport	(*No opinion*)	Moderate		Yes	
d) Large-Scale CO_2 Storage	Moderate	Moderate		Yes	Yes
e) Monitoring Stored CO_2	Moderate	Moderate		Yes	Yes
f) Mitigation / Remediation Procedures	Moderate	Very Slowly			Yes
g) Understanding Storage Reservoirs	Moderate	Very Slowly	Yes	Yes	
h) Infrastructure and the Integrated CCS Chain (capture to storage)	Moderate	Moderate	Yes	Yes	
i) CO_2 Utilization, non-EOR	Very Slowly	Very Slowly	Yes	Yes	Yes
j) CO_2 Utilization, EOR	Moderate	Moderate	Yes	Yes	Yes

Draft

Carbon Sequestration Leadership Forum
Form Revision date: 04 August 2014
www.cslforum.org

Tracking Progress in the Development of Technologies that will assist CCS Deployment

In 2013, the Carbon Sequestration Leadership Forum (CSLF) published a Technology Roadmap that is focused on addressing the following key questions:

- What is the current status of carbon capture and storage (CCS) technology and deployment?
- Where should CCS be by 2020 and beyond?

The CSLF is committed to maintaining its Technology Roadmap as a timely and accurate source of information about the global status of CCS. To that end, we welcome your evidence-based opinions concerning the status of technologies that will assist in the commercial implementation of large-scale CCS projects. **Please note that we are interested in progress in both application and adaption of first-generation technologies that are now being used in commercial or demonstration-scale CCS projects; and also second- and third-generation technologies that are being tested in pilot-scale CCS projects** (i.e., > 1 MW and/or > 1,000 tonnes of CO_2 injected per year). The CSLF Technology Roadmap covers decadal timeframes towards the years 2020, 2030, and 2050, but **this survey is only concerned with progress towards the year 2020**.

We invite you to summarize the relative progress in developing relevant technologies within your country (in Table 1) and globally (in Table 2). For each technology needs area shown in the tables (below), select one of four choices in the dropdown menu:

- **Very Slowly**
- **Moderate Progress**
- **Fast Moving**
- **No Opinion**

Please also indicate, by checking the appropriate boxes, if you believe there are economic, policy, and/or technological drivers/barriers that are affecting the relative amount of progress.

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TABLE 1: PROGRESS WITHIN YOUR COUNTRY

Technology Needs Area	1st Generation Technologies – Progress (toward 2020)	2nd – 3rd Gen. Technologies – Progress (toward 2020)	What are the drivers/barriers? (check all that apply)		
			Economic	Policy	Technology *(see below)*
k) CO_2 Capture in Power Generation	Choose an item.	Choose an item.	☐	☐	☐
l) CO_2 Capture in Industrial Sector	Choose an item.	Choose an item.	☐	☐	☐
m) CO_2 Transport	Choose an item.	Choose an item.	☐	☐	☐
n) Large-Scale CO_2 Storage	Choose an item.	Choose an item.	☐	☐	☐
o) Monitoring Stored CO_2	Choose an item.	Choose an item.	☐	☐	☐
p) Mitigation / Remediation Procedures	Choose an item.	Choose an item.	☐	☐	☐
q) Understanding Storage Reservoirs	Choose an item.	Choose an item.	☐	☐	☐
r) Infrastructure and the Integrated CCS Chain (capture to storage)	Choose an item.	Choose an item.	☐	☐	☐
s) CO_2 Utilization, non-EOR	Choose an item.	Choose an item.	☐	☐	☐
t) CO_2 Utilization, EOR	Choose an item.	Choose an item.	☐	☐	☐

TABLE 2: GLOBAL TRENDS

Technology Needs Area	1st Generation Technologies – Progress (toward 2020)	2nd – 3rd Gen. Technologies – Progress (toward 2020)	What are the drivers/barriers? (check all that apply)		
			Economic	Policy	Technology *(see below)*
a) CO_2 Capture in Power Generation	Choose an item.	Choose an item.	☐	☐	☐
b) CO_2 Capture in Industrial Sector	Choose an item.	Choose an item.	☐	☐	☐
c) CO_2 Transport	Choose an item.	Choose an item.	☐	☐	☐
d) Large-Scale CO_2 Storage	Choose an item.	Choose an item.	☐	☐	☐
e) Monitoring Stored CO_2	Choose an item.	Choose an item.	☐	☐	☐
f) Mitigation / Remediation Procedures	Choose an item.	Choose an item.	☐	☐	☐
g) Understanding Storage Reservoirs	Choose an item.	Choose an item.	☐	☐	☐
h) Infrastructure and the Integrated CCS Chain (capture to storage)	Choose an item.	Choose an item.	☐	☐	☐
i) CO_2 Utilization, non-EOR	Choose an item.	Choose an item.	☐	☐	☐
j) CO_2 Utilization, EOR	Choose an item.	Choose an item.	☐	☐	☐

Draft

If you checked any technology boxes in either of the two tables, please briefly describe any perceived technological barriers or advancements that influenced your opinion. Also please designate if these barriers/advancements pertain to first-generation technologies (i.e., for current large-scale projects) or to second- and third-generation technologies (i.e., pilot-scale).

a)
b)
c)
d)
e)
f)
g)
h)
i)
j)

Also, let us know of any recent publications and reports by your organization that is relevant to any of these areas (please also include links to these publications, if available).

a)
b)
c)
d)
e)
f)
g)
h)
i)
j)

Please return this tracking document to the CSLF Secretariat (cslfsecretariat@hq.doe.gov) when completed. We look forward to hearing from you!

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Carbon Sequestration Leadership Forum

www.cslforum.org

CSLF-T-2014-08
29 September 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. This Action Plan was updated at both the Washington meeting in November 2013 and the Seoul meeting in March 2014. Task forces were formed to address several of the actions in the Plan, while other actions have been deferred or canceled.

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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Carbon Sequestration Leadership Forum
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CSLF Technical Group Action Plan Status

(as of September 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.

- 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.

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: Reports for Years 2012 and 2013 have been issued. Findings of the task force will be archived at the CSLF website. The task force was discontinued in part because other organizations such as the European Commission's CO_2 GeoNet Project and the ISO TC265 committee on CCS may be planning similar activities.

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*). A linkage has been established with Global CCS Institute's low emissions technology website, decarboni.se, which now includes CSLF projects and reports. Also, Technical Group is holding annual technology workshops featuring representatives of CSLF-recognized projects.

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. A 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.

Offshore CO_2 Storage

Action: The Technical Group will provide a current assessment on the status of the global sub-seabed CO_2 storage potential, including potential for offshore EOR.

Outcome: Identification of technical barriers and challenges to sub-seabed CO_2 storage as well as RD&D opportunities. Also, identification of any potential opportunities for global collaboration. A previously-proposed Action on "CO_2 Compression and Transport" is being incorporated into this Action.

Status: A new task force (*led by the United States*) has been active since March 2014 and expects to have a progress report at the 2014 CSLF Annual Meeting and the draft of a final report by the time of the mid-year 2015 CSLF Meeting.

PROPOSED ACTIONS

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 the lead concerning this item and to report to the Technical Group on feasibility for activity in this area. Possible new task force would build on results from the United Kingdom's Cost Reduction Task Force. A final decision on whether to form a task force in this area will be made at the 2014 CSLF Annual Meeting.

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 the lead concerning this item (with support from the United States and the IEA GHG) and to report to the Technical Group on feasibility for activity in this area. Possible new task force would build on the Clean Energy Ministerial / IEA report that has been issued. A final decision on whether to form a task force in this area will be made at the 2014 CSLF Annual Meeting.

DRAFT

MEETING SUMMARY

Projects Interaction and Review Team (PIRT) Meeting
Seoul, Korea
24 March 2014

Prepared by the CSLF Secretariat

LIST OF ATTENDEES

PIRT Active Members ***(as of the beginning of the meeting)***

Australia:	Clinton Foster (Chair)
Canada:	Eddy Chui
European Commission:	Jeroen Schuppers
France:	Didier Bonijoly
Japan:	Ryozo Tanaka
Norway:	Trygve Riis, Lars Ingolf Eide
Saudi Arabia:	Ahmed Aleidan
South Africa:	Tony Surridge
United Kingdom:	Philip Sharman
United States:	Mark Ackiewicz
IEA GHG:	Tim Dixon

Other CSLF Delegates

Australia:	Richard Aldous
Canada:	Stefan Bachu
China:	Jiutian Zhang, Xiaochun Li
Korea:	Chong Kul Ryu, Chang Keun Yi
Mexico:	Edgar Santoyo-Castelazo
Netherlands:	Paul Ramsak
Saudi Arabia:	Hamoud Alotaibi
United States:	Geo Richards

CSLF Secretariat Richard Lynch

Observers

Korea:	Seong Jegarl
United States:	John Harju, Edward Steadman

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Return to PIRT Agenda

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

PIRT Chairman Clinton Foster welcomed participants to the 21st meeting of the PIRT and provided a brief summary of the November 2013 PIRT meeting in Washington. At that meeting the PIRT reached consensus on the following:

- The PIRT recommended approval by the Technical Group for three projects: the Kemper County Energy Facility, the Southeast Regional Carbon Sequestration Partnership (SECARB) Phase III Anthropogenic Test and Plant Barry CCS Project, and the Midwest Region Carbon Sequestration Partnership (MRCSP) Development Phase Project.
- The PIRT agreed to an update to the PIRT Terms of Reference and an update to the CSLF Project Submission Form.

Dr. Foster then called on Richard Lynch, who stated that John Panek had received a new assignment and would not be representing the CSLF Secretariat at the current PIRT and Technical Group meetings. Dr. Foster expressed his appreciation to Mr. Panek, who had diligently represented the CSLF Secretariat at PIRT meetings since 2005. The meeting attendees also expressed their appreciation for Mr. Panek with a round of applause.

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 Washington PIRT Meeting**

The Meeting Summary from the November 2013 PIRT meeting in Washington was approved as final with the following changes:

- Remove the three questions shown under "Project Timeline" in the Revised Project Submission Form attachment to the Meeting Summary. There had been consensus at the previous PIRT meeting to eliminate these questions, but they had inadvertently been included in the version of the Revised Form appended to the Meeting Summary.
- In the descriptions of the three projects nominated for CSLF recognition, change "After brief discussion, there was consensus by the PIRT to recommend…" to: "After a comprehensive discussion, there was consensus by the PIRT to recommend…" This change reflects the additional level of analysis done by the PIRT relative to the Technical Group concerning approval of nominated projects.

Dr. Foster noted that there had been two action items from the meeting:

- The CSLF Secretariat was requested to prepare newly updated versions of the PIRT Terms of Reference and the CSLF Project Submission Form, incorporating edits approved during the PIRT meeting.
- The PIRT Chair was to obtain further information from the Global Carbon Capture and Storage Institute (GCCSI) about its proposal for a co-branded CSLF-GCCSI Knowledge Hub website and other GCCSI knowledge sharing activities relevant to the PIRT.

Dr. Foster stated that both of these had been completed, and that the knowledge-sharing was an upcoming item on the current meeting's agenda.

5. **Update on PIRT Membership**

Dr. Foster noted that the updated PIRT Terms of Reference document that was ratified at the November 2013 meeting in Washington redefined the PIRT as a core group of active members comprised of CSLF Technical Group delegates and/or other CCS experts nominated by CSLF Member countries, and also an *ad-hoc* group of stakeholders comprised of representatives from CSLF-recognized projects. As of the beginning of the current meeting, ten CSLF Members as well as the IEA Greenhouse Gas R&D Programme (IEA GHG) had designated representatives to the PIRT core group. Dr. Foster inquired if there were any more volunteers to join the core group, which resulted in three new active members being added: Jiutian Zhang (China), Edgar Santoyo-Castelazo (Mexico), and Paul Ramsak (Netherlands).

6. **Discussion of Knowledge-Sharing from CSLF-Recognized Projects**

Dr. Foster stated that Sean McClowry, the General Manager for Information Management at the GCCSI, was not able to be at this meeting but had provided a presentation about the new "**decarboni.se**" website. This is an "unbranded" website, created and managed by the GCCSI, which is intended to be a repository of information related to low-emissions technologies, including CCS. The website was created to facilitate knowledge-sharing, and includes publications, news items, and op-ed insights related to these technologies. Dr. Foster stated that that the intention of this website is to be a knowledge hub for these technologies, providing platforms for organizations and corporations to build knowledge-sharing mini-websites within the knowledge hub. The CSLF is one of more than 400 such organizations.

Ensuing discussion attempted to clarify how information is brought into **decarboni.se** and who is responsible for providing and collecting this information. Dr. Foster noted that, at present, the GCCSI Information Management Team is exclusively responsible for populating the website, though specifics are needed on how this is done and what kinds of information are being featured. In the end, there was consensus that the PIRT include updates from the GCCSI about **decarboni.se** and other CCS-related knowledge-sharing activities in its meetings, and that the Secretariat should add a link to **decarboni.se** from the CSLF website.

7. **Update Plan for CSLF Technology Roadmap**

Dr. Foster stated that as of the 2013 CSLF Ministerial Meeting, the PIRT has assumed responsibility for the CSLF Technology Roadmap (TRM), including producing future updates on a schedule as determined by the Technical Group. To accomplish this, the 2013 TRM provides that the PIRT, through the CSLF Secretariat, will:

- Solicit input with respect to progress of CCS from all CSLF delegations;
- Gather information from a wide range of sources on the global progress of CCS;
- Prepare a simple reporting template for the eight "Identified Technology Needs" from the 2013 TRM;
- Report annually to the CSLF Technical Group; and
- Report biennially, or as required, at CSLF Ministerial Meetings.

To that end, Dr. Foster proposed that a questionnaire or information-gathering template of some kind be developed for sending to representatives of organizations that are actively working on various aspects of CCS. There was general agreement on this approach and after much discussion on how it should be implemented there was consensus on the following plan of action:

- The CSLF Secretariat will prepare a template for gathering information on the eight "Identified Technology Needs" areas, and send the template to outside organizations.
- PIRT Active Members will be responsible for parsing through information gathered in order to determine and monitor worldwide progress in each of these areas.

Dr. Foster stated that the results of this survey would be used to develop a 2014 Progress Report Addendum for the 2013 TRM and potentially a 2015 Interim Report for the next CSLF Ministerial Meeting. There would not be a major rewrite of the TRM until 2017, in time for another Ministerial Meeting. There was agreement for this timeline, and after a call for volunteers to take charge of information analysis for each of the eight needs areas, the following responsibilities were assigned:

Area #1: CO_2 Capture Technologies in Power Generation (*Norway*)

Area #2: CO_2 Capture in Industrial Sector (*South Africa* and *United Kingdom*)

Area #3: CO_2 Transport (*Australia*)

Area #4: Large-Scale CO_2 Storage (*Japan* and *France*)

Area #5a: Monitoring (*United States* and *France*)

Area #5b: Mitigation / Remediation (*European Commission*)

Area #6: Understanding the Storage Reservoirs (*United Kingdom* – to be confirmed)

Area #7: Infrastructure (*United Kingdom* – to be confirmed)

Area #8a: CO_2 Utilization, non-EOR (*France* – to be confirmed)

Area #8b: CO_2 Utilization, EOR (*Saudi Arabia*)

Philip Sharman complimented Dr. Foster for his preparation of the graphical timetable of PIRT activities, which Mr. Sharman described as the best he had ever seen. Mr. Sharman noted that while this timeline may very well change, it was still an excellent starting point. (*Note: the graphical PIRT timeline is appended to this Meeting Summary*.)

8. PIRT Action Plan

Dr. Foster noted that the TRM activities were just one part of the overall PIRT Action Plan. There are also some 'business-as-usual' (BAU) activities such as review of projects nominated for CSLF recognition, knowledge sharing, and planning of future technology workshops. Dr. Foster stated that the PIRT had recently updated its Terms of Reference, and may need further refining of its areas of activities during the roll-up toward a 2017 Ministerial Meeting. Updating the PIRT Action Plan will most likely become one of the PIRT's BAU activities.

9. Adjourn

Dr. Foster thanked the attendees for their participation, expressed his appreciation to the host Korean delegation for its hospitality, and adjourned the meeting.

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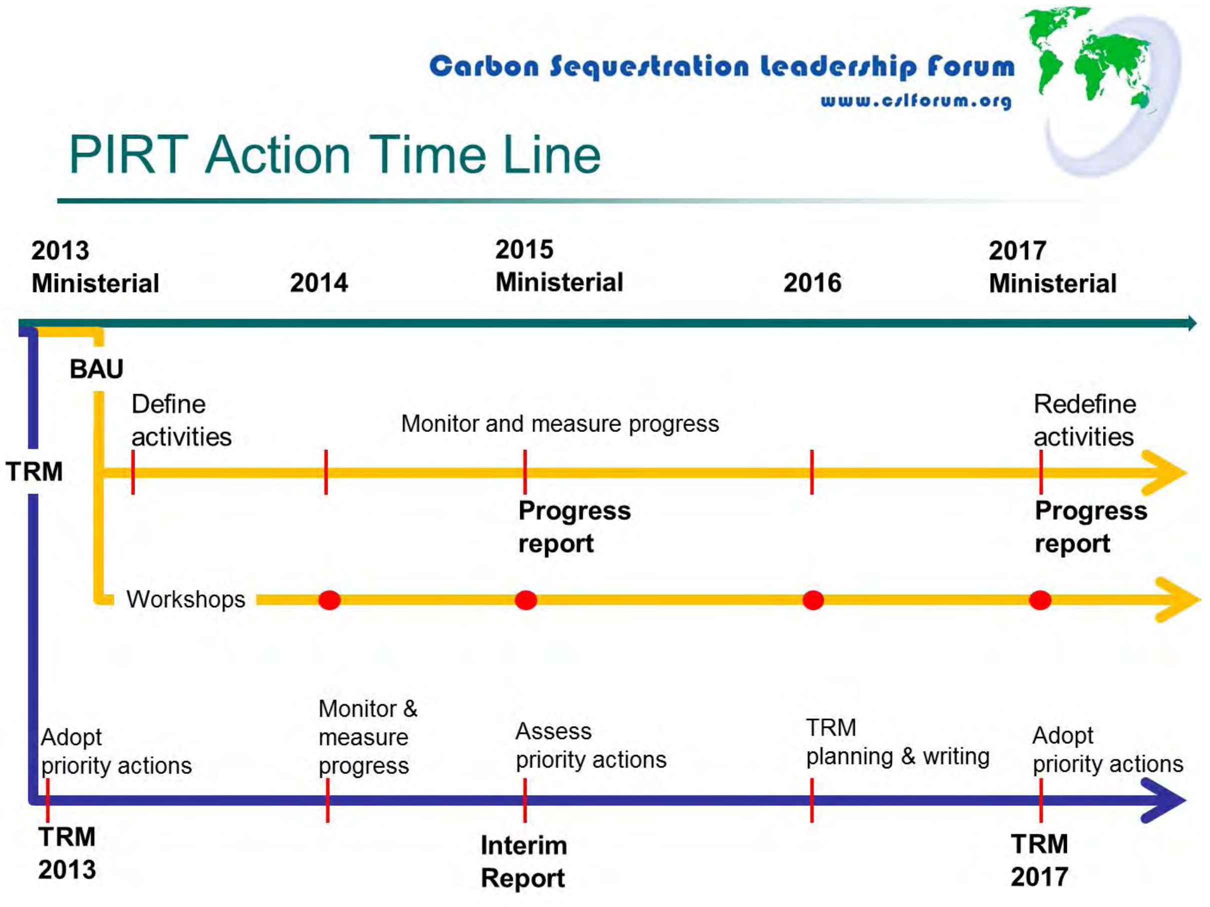
Return to PIRT Agenda

Summary of Consensuses

- Three new members are added to the PIRT's active membership core group.
- PIRT meetings will include updates from the GCCSI about its **decarboni.se** knowledge hub website and other CCS-related knowledge-sharing activities.

Summary of Action Items

- The Secretariat will finalize the Summary for the November 2013 PIRT meeting including the modifications described above.
- The Secretariat will add a link from the CSLF website to the GCCSI's new **decarboni.se** website.
- The Secretariat will develop a template for use in gathering information on the eight "Identified Technology Needs" areas identified by the 2013 TRM. The template will be approved by the PIRT Chair prior to its use.
- The Secretariat will send the template to representatives of organizations that are actively working on various aspects of CCS to obtain information that can be used to determine and monitor worldwide progress on CCS.
- PIRT Active Members, as designated above, will take charge of information analysis for the eight needs areas once information gathering is complete.
- The PIRT will produce a 2014 Progress Report Addendum for the 2013 TRM.



Carbon Sequestration Leadership Forum

Revised: November 2013

www.cslforum.org

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.

- 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

www.cslforum.org

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

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, ensuring it to be 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 Conduct such other activities to advance achievement of the CSLF's purpose as the Members may determine;

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

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

2.14 Support international efforts to promote RD&D and capacity building projects in developing countries.

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 will 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 will 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 the 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 will 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)

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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 will 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 will be 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.

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.

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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.

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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.

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. Decision Making. 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. Types of Collaborative Projects. 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. Project Recognition. 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.

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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.

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

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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

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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

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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

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

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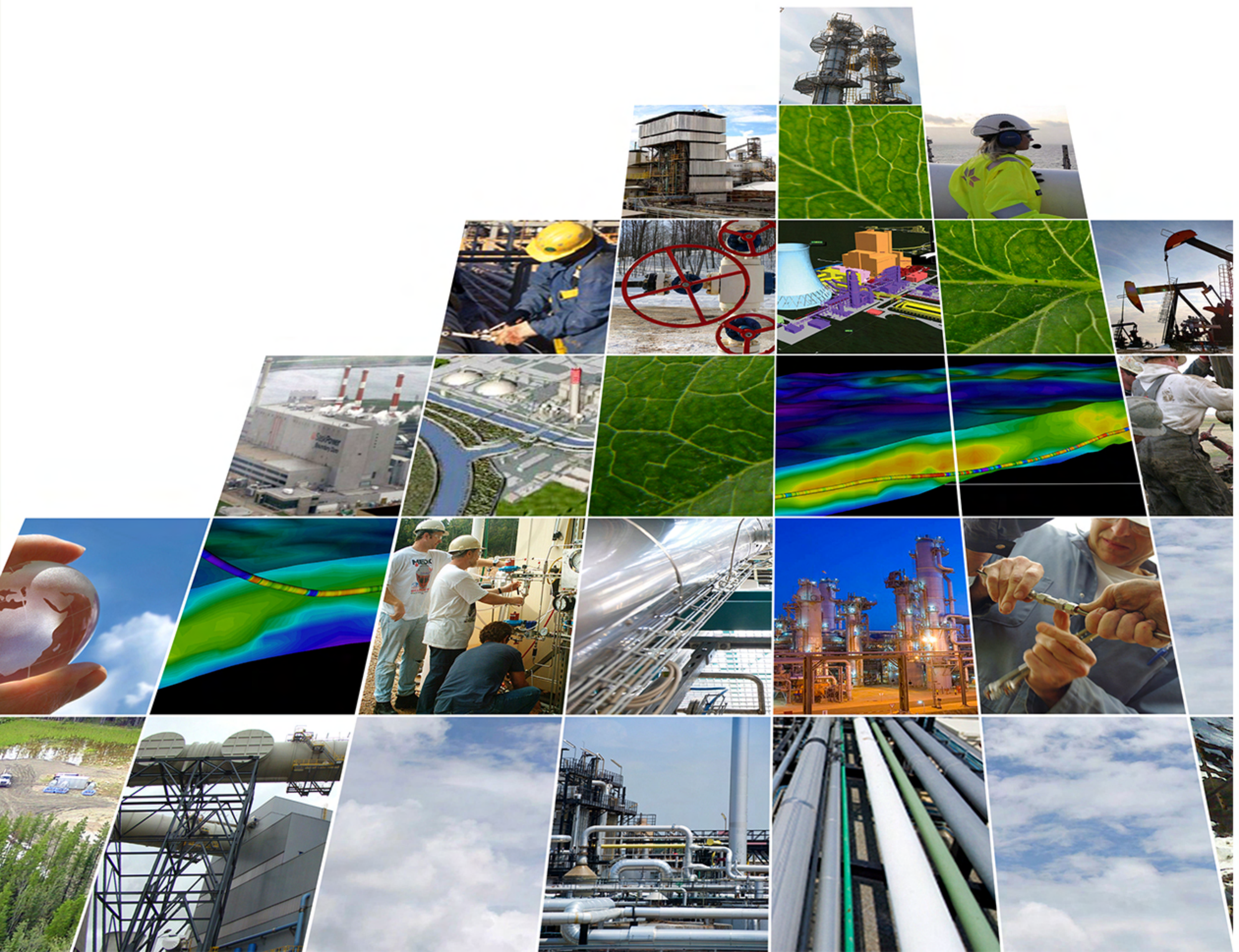
carbon sequestration leadership forum

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.

- 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°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*

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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

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[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.

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.

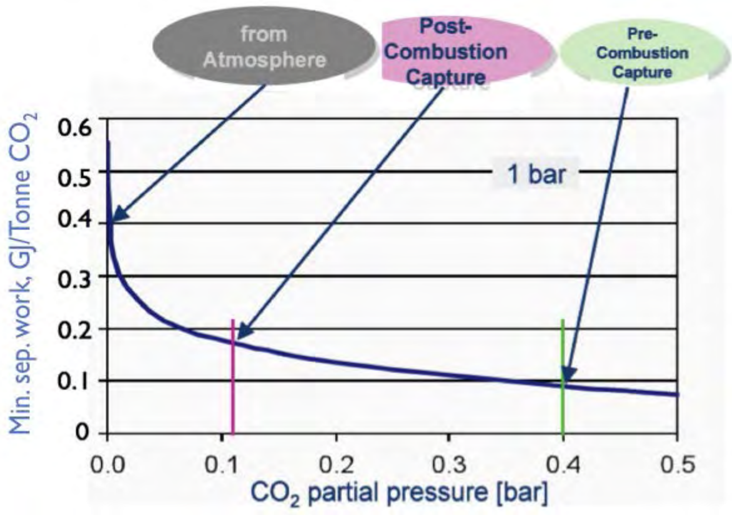

Figure 1: Theoretical minimum separation work of CO_2 from a flue gas depending on the partial pressure of CO_2 [modified from Bolland et al., 2006]

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.

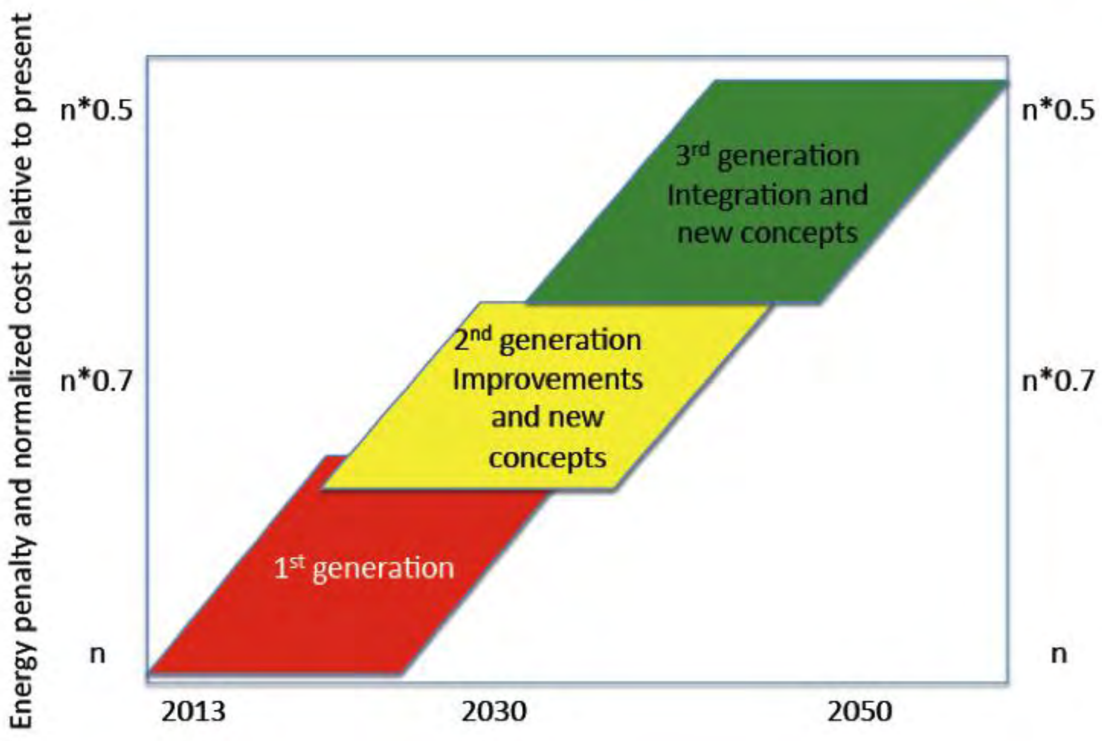

Figure 2: Priorities for CCS technology development. The energy penalty and normalized costs are shown in relation to the present level (n), i.e. equivalent to reduction by 30% in 2030 and 50% towards 2050.

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.

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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.

<u>Towards 2030 nations should work together to:</u>

- 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.

<u>Towards 2050 nations should work together to:</u>

- 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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