CSLF Annual Meeting
October 3-7, 2016
Tokyo, Japan

carbon
sequestration leadership forum

MEETING DOCUMENTS BOOK

Carbon Sequestration Leadership Forum

www.cslforum.org

2016 CSLF ANNUAL MEETING DOCUMENTS BOOK

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Carbon Sequestration Leadership Forum

www.cslforum.org

2016 CSLF Annual Meeting

Tokyo, Japan

03-07 October 2016

	Monday 03 October 2016	Tuesday 04 October 2016	Wednesday 05 October 2016	Thursday 06 October 2016	Friday 07 October 2016
Morning		CSLF Technical Group Meeting	CSLF Workshop	Site Tour to Tomakomai Project* (day trip from Tokyo)	CSLF Policy Group Meeting
Afternoon	CSLF Projects Interaction and Review Team (PIRT) Meeting	CSLF Technical Group Meeting (continues)	CSLF Workshop (continues)	Site Tour to Tomakomai Project* (continues)	CSLF Policy Group Meeting (continues)
Evening		Dinner: "Asuka" Room, Hotel Azur Takeshiba. 1-11-2 Kaigan, Minato-ku, Tokyo, 105-0022	Reception		Dinner: Ganko Ginza 1-Chome. 1-7-10, Ginza Fuji Bldg., Ginza, Chuo-ku, Tokyo 104-0061

* Site tour participants are required to arrange flights between Haneda Airport and New Chitose Airport.

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Meeting Venue Information

Meeting Venue

The 2016 CSLF Annual Meeting will be in Tokyo, Japan at **Fukuracia Tokyo Station** (5-6th floor, Asahi-seimei Otemachi Building, Otemachi 2-6-1, Chiyoda-ku, Tokyo) from Monday, October 3 through Friday, October 7. (Map showing location of venue is on next page, below.).

Hotel Room Block

A block of rooms has been set aside for meeting attendees in five hotels, as shown in the table. You can reserve one of these rooms at http://nittsu-ryoko.co.jp/event/cslf/english.html by September 15.

Hotel	Room Type	Fee per night *	10/1 (Sat)	10/2 (Sun)	10/3 (Mon)	10/4 (Tue)	10/5 (Wed)	10/6 (Thu)	10/7 (Fri)	10/8 (Sat)	Access to the venue
1. Marunouchi Hotel	Single room	JPY 27,800	10	10	10	10	10	10	10	0	1 min walk
	Twin for 1	JPY 34,500	3	3	3	3	3	3	3	0	
	Twin for 2	JPY 44,800									
2. Hotel Metropolitan Marunouchi	Single	JPY 26,800	8	12	12	12	12	12	12	8	1 min walk
	Twin for 1	JPY 43,600	0	4	4	4	4	4	4	0	
	Twin for 2	JPY 43,600									
3. Hotel Ryumeikan Tokyo	Single room	JPY 25,800	10	10	10	10	10	10	10	10	3 mins walk
4. Keio Presso Inn Otemachi	Single room	JPY 10,500	20	20	20	20	20	20	20	20	7 mins walk
5. Pearl Hotel Kayabachou	Single room	JPY 9,800	15	15	15	15	15	15	15	15	15 mins walk
	Twin for 1	JPY 14,000	3	3	3	3	3	3	3	3	
	Twin for 2	JPY 18,000									

* Including breakfast and tax

VISA Application

For assistance in obtaining a visa to enter Japan, please contact the Ministry of Economy, Trade and Industry (ETI) at CSLF_VISA@meti.go.jp. Please refer to the "2016 CSLF Annual Meeting" in your email.

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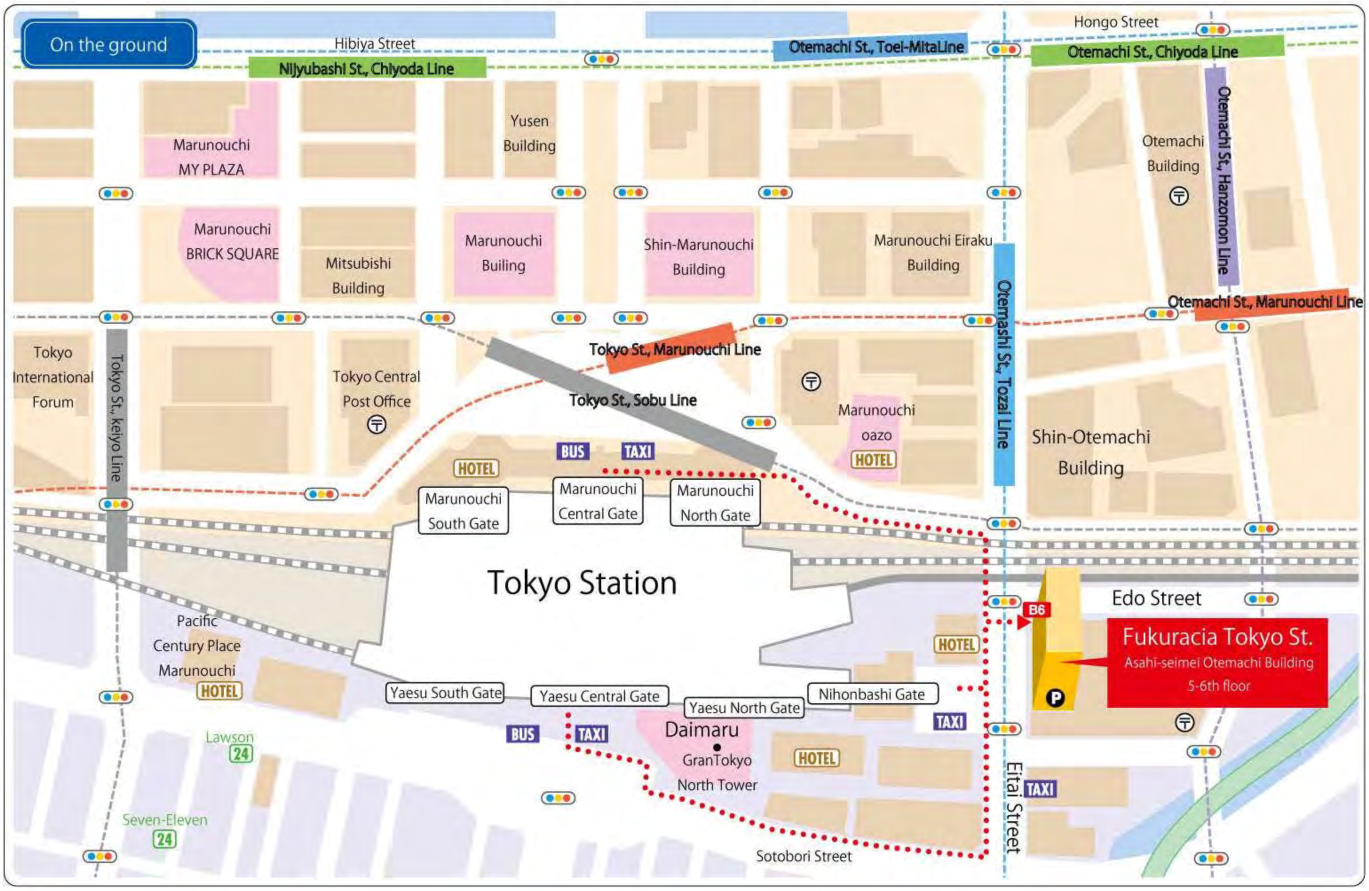
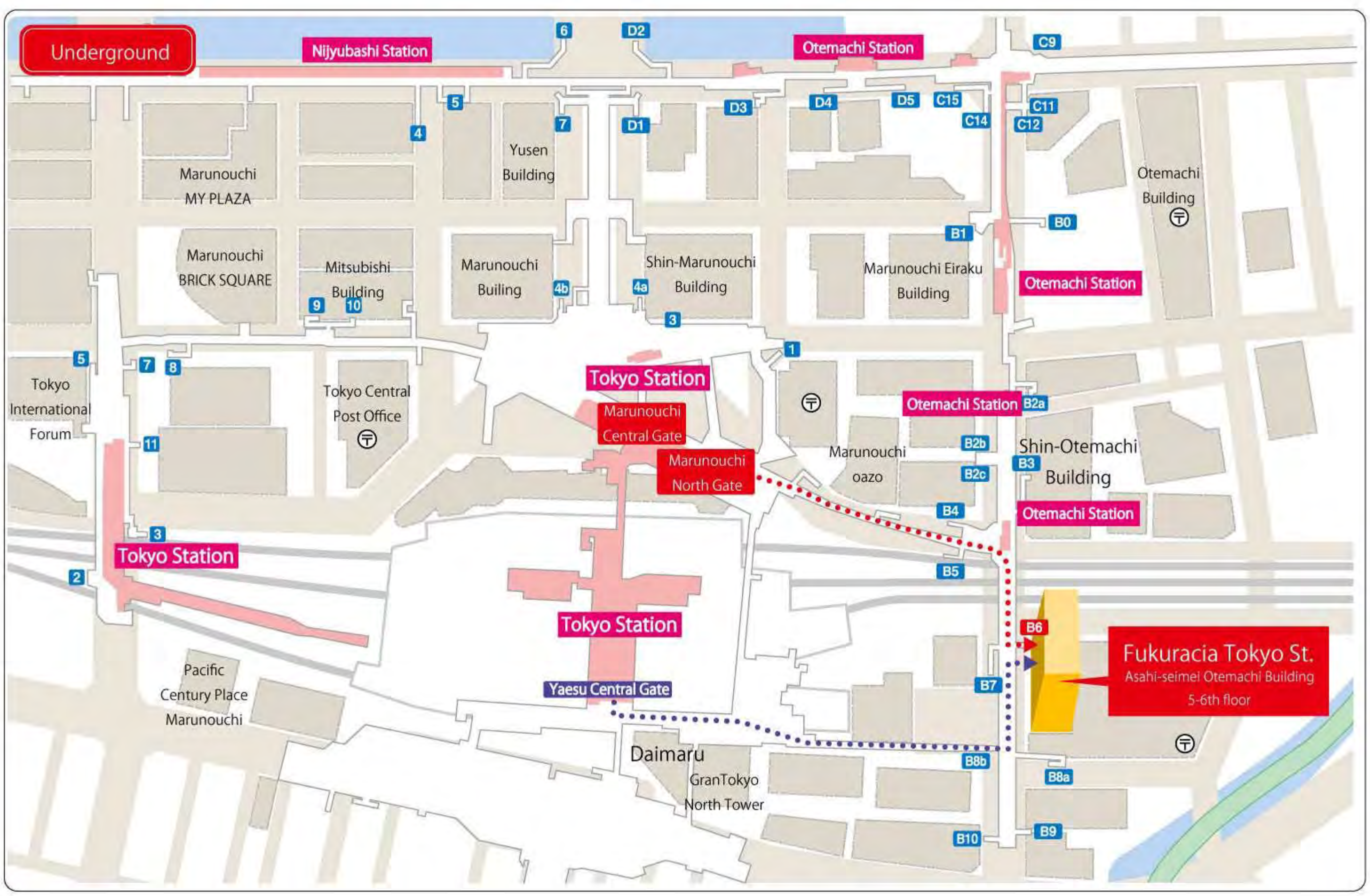
FUKURACIA TOKYO St.

Asahi-seimei Otemachi Building 5-6 th floor,
Otemachi 2-6-1, Chiyoda-ku,Tokyo





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Carbon Sequestration Leadership Forum

www.cslforum.org

Draft: 23 September 2016
Prepared by CSLF Secretariat

Draft Agenda

CSLF PROJECTS INTERACTION AND REVIEW TEAM (PIRT)

Fukuracia Tokyo Station
Room "C", 6th floor, Asahi-seimei
Otemachi Building, Otemachi 2-6-1, Chiyoda-ku
Tokyo, Japan

03 October 2016

13:00-16:30

1. **Welcome and Opening Remarks**
   Andrew Barrett, PIRT Chair, Australia

2. **Introduction of Attendees**
   Meeting Attendees

3. **Adoption of Agenda**
   Andrew Barrett, PIRT Chair, Australia

4. **Approval of Summary from London PIRT Meeting**
   Andrew Barrett, PIRT Chair, Australia

5. **Report from Secretariat**
   - Review of London PIRT Meeting
   - Summary of CSLF Recognized Projects

   Richard Lynch, CSLF Secretariat

6. **2017 CSLF Technology Roadmap (TRM) Progress Report**
   Andrew Barrett, PIRT Chair, Australia

7. **Review of Project Proposed for CSLF Recognition:**
   Tomakomai CCS Demonstration Project
   Yukata Tanaka, JCCS, Japan

8. **Review of Project Proposed for CSLF Recognition:**
   NET Power 50MWth Allam Cycle Demonstration Project
   Hideo Nomoto, 8 Rivers and NET Power, United States

9. **Proposed Revision to CSLF Project Submission Form**
   Richard Lynch, CSLF Secretariat

10. **Engaging CSLF-recognized Projects**
    Richard Lynch, CSLF Secretariat
    PIRT Delegates and Meeting Attendees

11. **Open Discussion on Possible New Technical Group Activities** CSLF-T-2016-07
    Åse Slagtern, Technical Group Chair, Norway
    PIRT Delegates and Meeting Attendees

12. **General Discussion and New Business**
    PIRT Delegates and Meeting Attendees

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

14. Closing Comments / Adjourn
Andrew Barrett, PIRT Chair, Australia

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CSLF-T-2016-06
Draft: 23 September 2016
Prepared by CSLF Secretariat

DRAFT AGENDA
CSLF Technical Group Meeting

Fukuracia Tokyo Station
Room "K", 5th floor, Asahi-seimei
Otemachi Building, Otemachi 2-6-1, Chiyoda-ku
Tokyo, Japan

04 October 2016

08:00-09:00 Meeting Registration

09:00-10:30 Technical Group Meeting

1. **Welcome and Opening Statement**
   Åse Slagtern, Technical Group Chair, Norway

2. **Host Country Welcome**
   Yoichi Kaya, RITE, Japan

3. **Introduction of Delegates**
   Delegates

4. **Adoption of Agenda**
   Åse Slagtern, Technical Group Chair, Norway

5. **Review and Approval of Minutes from London Meeting** CSLF-T-2016-05
   Åse Slagtern, Technical Group Chair, Norway

6. **Report from Secretariat**
   - Highlights from June 2016 Mid-Year Meeting
   - Review of London Meeting Action Items

   Richard Lynch, CSLF Secretariat

7. **Overview of CCS-related Activities in Japan**
   Takashi Kawabata, METI, Japan

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

9. **Update from the Global CCS Institute**
   Alex Zapantis, GCCSI

10:30-10:45 Refreshment Break

10:45-12:00 Continuation of Meeting

10. **Report from Projects Interaction and Review Team**
    Andrew Barrett, PIRT Chair, Australia

11. **Progress Report on next CSLF Technology Roadmap**
    Andrew Barrett, Working Group Chair, Australia

12. **Report from Off-Shore CO_2-EOR Task Force**
    Lars Ingolf Eide, Task Force Chair, Norway

13. Report from Bioenergy with CCS Task Force
John Litynski, Task Force Chair, United States

14. Report from Improved Pore Space Utilisation Task Force
Max Watson, Task Force Co-Chair, Australia
Brian Allison, Task Force Co-Chair, United Kingdom

12:00-13:30 Lunch

13:30-15:50 Continuation of Meeting

15. Review of Technical Group Action Plan and Possible New Technical Group Activities CSLF-T-2016-07
Åse Slagtern, Technical Group Chair, Norway

16. Review of Project Nominated for CSLF Recognition: Tomakomai CCS Demonstration Project
Jiro Tanaka, JCCS, Japan

17. Review of Project Nominated for CSLF Recognition: NET Power 50MWth Allam Cycle Demonstration Project
Hideo Nomoto, 8 Rivers and NET Power, United States

18. Life-Cycle Emissions Estimates for Bio-Fuels with CCS
Sean McCoy, Lawrence Livermore National Laboratory, United States

19. Transforming CO_2 into Commercial Products
Issam Dairanieh, Global CO_2 Initiative, United States

15:50-16:00 Refreshment Break

16:00-17:15 Continuation of Meeting

20. Pathway to Low-Carbon Lignite Utilization: a Partnership of Resource Owners/Developers, Energy Producers, State & Federal Government, Technology Developers, and Research Providers
Thomas A. Erickson, EETC, United States

21. Results from CSLF-recognized Project: CO_2 Separation from Pressurized Gas Stream
Shinichi Nakao, RITE, Japan

22. Recent Activity of ISO/TC265/WG1 on Capture
Takayuki Higashii, ISO/TC265/WG1 Convenor, Japan

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

24. Open Discussion and New Business
Delegates

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

26. Closing Remarks / Adjourn
Åse Slagtern, Technical Group Chair, Norway

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2016 CSLF Technical Workshop

Room K, Fukuracia Tokyo Station,
5th floor, Asahi-seimei Otemachi Building, Otemachi 2-6-1, Chiyoda-ku, Tokyo, Japan
5 October 2016

The CSLF Technical Workshop is aimed at promoting knowledge sharing regarding CCUS technology for CCUS experts, including CSLF delegates. The first session is designed to facilitate potential and ongoing CSLF taskforces – industrial CCS, offshore EOR and improved pore space utilization. Session 2 is arranged to enhance knowledge sharing from existing five large-scale CCS projects, most of which are CSLF recognized projects. The final session places the focus on the future of industrial CCS, looking into potential projects and infrastructure to be required for its wider deployment. The workshop is also expected to expand and strengthen expert network toward wider CCUS deployment in future.

The length of each presentation is 30 minutes, including 5-minute Q&A session.

8:30-9:00 **Registration**

9:00-9:20 **Opening Session**

- **Opening Address**
  Kenji Yamaji, RITE

9:20-10:20 **Session 1: Input to Ongoing and Potential CSLF Taskforces**
Session Chair: *Richard Lynch, CSLF Secretariat*

- **Overview of industrial CCS**
  Alex Zapantis, GCCSI
- **Offshore CO_2-EOR Pilot Project in Vietnam**
  Yohei Kawahara, JX Nippon Oil & Gas Exploration

10:20-10:50 **Coffee Break (Room L)**

10:50-11:20 **Session 1: Input to Ongoing and Potential CSLF Taskforces *(continued)***
Session Chair: *Richard Lynch, CSLF Secretariat*

- **Micro bubble CO_2 injection**
  Ziqiu Xue, RITE

11:20-12:20 Session 2: Lesson Learned from Large-Scale CCS Projects

Session Chair: *Lars Ingolf Eide, Research Council of Norway*

- **Uthmaniyah CO_2-EOR Demonstration Project**
  Ammar Alshehri, Saudi Aramco
- **Illinois Decatur Basin Project**
  Sallie Greenberg, University of Illinois

12:20-13:45 Lunch (Room L, sponsored by GCCSI)

13:00-13:45 Poster Session (Room L)

13:45-15:15 Session 2: Lesson Learned from Large-Scale CCS Projects *(continued)*

Session Chair: *Lars Ingolf Eide, Research Council of Norway*

- **Lacq Integrated CCS Project**
  Dominique Copin, Total
- **Petra Nova CCS Project**
  Greg Kennedy, NRG Energy
  Tatsuya Tsubatani, JX Nippon Oil & Gas Exploration
- **Plant Barry CO_2 Capture Project**
  Takashi Kamijo, Mitsubishi Heavy Industries (MHI)

15:15-15:45 Coffee Break (Room L)

15:45-17:15 Session 3: Future of Industrial CCS

Session Chair: *Ryozo Tanaka, RITE*

- **Industrial CCS Feasibility Studies in Norway**
  Trude Sundset, Gassnova
- **CO_2-Free Hydrogen Supply Chain**
  Ryo Chishiro, Kawasaki Heavy Industries (KHI)
- **Hubs and Clusters for Industrial CCS**
  John Thompson, Clear Air Taskforce

17:15-17:30 Closing Session

- **Wrap-up**
  Ryozo Tanaka, RITE
- **Closing Remarks**
  Åse Slagtern, CSLF Technical Group Chair

17:30-19:00 Reception (Room L, hosted by RITE)

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2016 CSLF Annual Meeting, Tokyo, Japan

Site Visit to the Tomakomai CCS Demonstration Site, Hokkaido
October 6, 2016

Note: Participants are required to arrange their own air travel between Haneda Airport and New Chitose Airport. See below for recommended flights.

Schedule of Site Visit:

07:45	Bus departs from Fukuracia Tokyo Station to Haneda Airport (*see page 2*)
08:30	Bus arrives Haneda Airport
09:30	Flights depart airport (*see below*)
11:05	Flights arrive New Chitose Airport
11:20	Meet up at New Chitose Airport (*see page 3*)
11:35	Depart from New Chitose Airport by bus
12:15	Lunch at Grand Hotel New Oji
13:05	Depart for Tomakomai CCS Demonstration Site by bus
13:40	Tour of Tomakomai CCS Demonstration Site
15:40	Depart for New Chitose Airport by bus
16:20	Arrive at New Chitose Airport
17:25	Flights depart airport (*see below*)
19:05	Flights arrive Haneda Airport
19:30 (tbc)	Bus departs Haneda Airport for Fukuracia Tokyo Station
20:15 (tbc)	Bus arrives Fukuracia Tokyo Station

Flights Recommended:
From Haneda to New Chitose:

- JAL 509 / Departure at 09:30, Arrival at 11:05
- ANA 057 / Departure at 09:30, Arrival at 11:05

Anyone who will be checking luggage should take an earlier flight, as the meet-up at the bus will happen very soon after the flights arrive at New Chitose Airport.

For those who take either of the recommended flights, a bus transport is arranged in Tokyo, leaving near the meeting venue Fukuracia Tokyo Station and arriving at Haneda Airport.

Other transport to the airport can be found at the following website:
https://www.tokyo-airport-bldg.co.jp/en/access/route_master/

From New Chitose to Haneda:

- JAL 520 / Departure at 17:25, Arrival at 19:05
- ANA 074 / Departure at 17:30, Arrival at 19:05

For those who take either of these flights, a bus transport is arranged from Haneda Airport to near Fukuracia Tokyo Station. Other transport can be found via the above website.

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Meeting Point for Bus Transport from the Meeting Venue to Haneda Airport
Bus departure time: 7:45

Meeting point: Outside of the entrance of Asahi-seimei Otemachi Building, 5th and 6th floors of which is the meeting venue, Fukurashia Tokyo Station

N.B. Please be punctual. Our bus cannot stop more than five minutes on the street.

Overview of Asahi-seimei Otemachi Building

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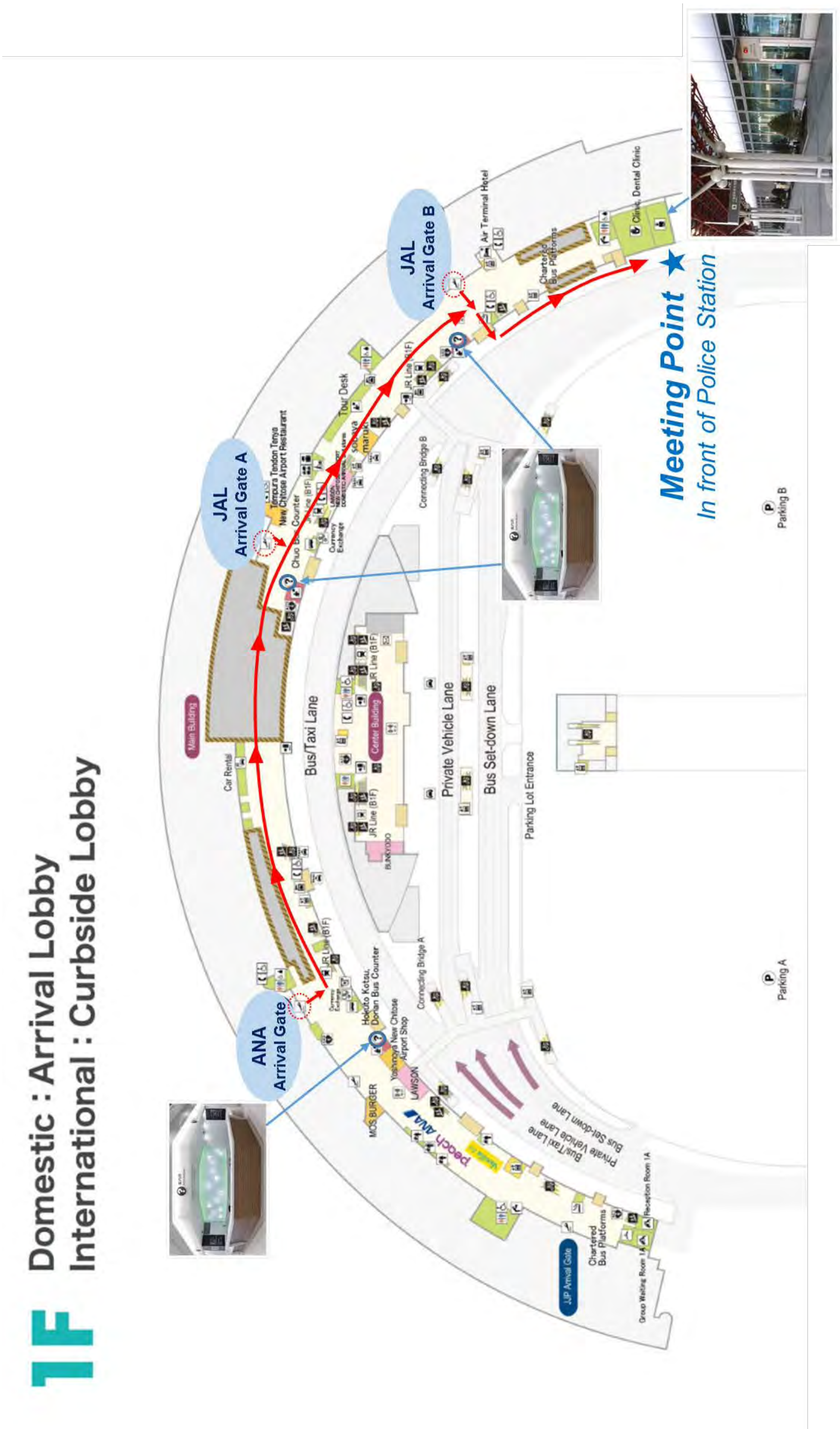
Meeting Point - the Entrance of Asahi-seimei Otemachi Building

Meeting Point at New Chitose Airport

Meet-up time: 11:20

Bus departure time: 11:35



Overview of Tomakomai CCS Demonstration Project in Hokkaido

Tomakomai CCS Demonstration Project is a large-scale CCS demonstration project which is currently being undertaken by the Japanese government in the Tomakomai area, Hokkaido prefecture, Japan. The project objective is to demonstrate the viability of a full CCS system, from CO_2 capture to injection and storage. One hundred thousand tons per year or more of CO_2 will be injected and stored in offshore saline aquifers in the Tomakomai port area. The implementation of this project has been commissioned to Japan CCS Co., Ltd. Since April 2016, CO2 capture and injection has started at the rate of around 100 thousand tons per year of CO2.

The main features of this project are as follows:

- **Schedule:** Construction of the facilities was completed in October 2015, and test-run of the facilities also successfully finished in February 2016. CO_2 capture, injection & monitoring is conducted from 2016 to 2018 and monitoring will be continued until 2020.
- **CO_2 Source:** Hydrogen Production Unit of adjacent oil refinery
- **Capture type:** Industrial separation-chemical absorption (amine); two-stage CO_2 capture system provides for low energy consumption
- **Storage Formation:** Sandstone layer at 1,000-1,200m depth & volcanic rocks at 2,400-3,000m depth
- **Drilling:** CO_2 injection wells were drilled from an onshore site directionally into offshore reservoirs, greatly saving drilling and maintenance costs. Notably, the shallow reservoir was reached by Extended Reach Drilling (ERD).
- **Monitoring:** Extensive monitoring system comprised of observation wells, onshore seismometer, ocean bottom seismometers, ocean bottom cable to monitor natural earthquakes and micro-seismicity in order to verify that natural earthquakes do not affect CO_2 injection, and CO_2 injection does not induce noticeable tremors.
- **Regulation:** Marine environmental monitoring is being conducted based on "Act on Prevention of Marine Pollution and Maritime Disaster" which complies with London 1996 Protocol.
- **Public Outreach:** The project is the first case of CCS near urban area; good relationships with local communities have been maintained as a result of extensive public outreach activities.

About Tomakomai City, Hokkaido

The City of Tomakomai is on the Pacific Ocean side of Hokkaido. With a population of approximately 173,000, Tomakomai is the largest international trading port and a major hub in Hokkaido's economy, handling about a third of the island's cargo volume. Many industries are located along Tomakomai's waterfront area, such as oil refineries, automobile manufacturers, power plants, paper mills and chemical plants. It is also an oil and gas producing area with a large gas field located inside the city. Fishery is also a major industry in Tomakomai, and a local specialty is the Hokki shellfish (surf clam).

Tomakomai places great emphasis on the preservation of its natural environment. The Utonai bird sanctuary, registered as the forth Ramsar site in 1991 is an important stopover for migratory birds. There are also many scenic spots in and around town such as Mt. Tarumae and Lake Shikotsu.

In October, the average temperature is 11.3 ^{o}C, and the average high and low temperatures are 15.8 ^{o}C and 6.1 ^{o}C, respectively.

Lake Utonai

Mt. Tarumae

Lake Shikotsu

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Carbon Sequestration Leadership Forum
www.cslforum.org

CSLF-P-2016-04
Draft: 28 September 2016
Prepared by CSLF Secretariat

DRAFT AGENDA
CSLF Policy Group Meeting

Fukuracia Tokyo Station
Room "K", 5th floor, Asahi-seimei
Otemachi Building, Otemachi 2-6-1, Chiyoda-ku
Tokyo, Japan

Friday, October 7, 2016

08:00-09:00 Meeting Registration

09:00-10:30 Policy Group Meeting

1. **Welcome and Opening Statement**
   Jarad Daniels, Policy Group Chair, United States

2. **Meeting Host's Welcome**
   Wataru Matsumura, Ministry of Economy, Trade and Industry (METI), Japan

3. **Climate Goals and CCS**
   Kenji Yamaji, The Research Institute of Innovative Technology for the Earth (RITE), Japan

4. **Introduction of Delegates**
   Delegates

5. **Adoption of Agenda**
   Jarad Daniels, Policy Group Chair, United States

6. **Review and Approval of Minutes from London Meeting** CSLF-P-2016-03
   Jarad Daniels, Policy Group Chair, United States

7. **Review of London Meeting Action Items**
   Stephanie Duran, CSLF Secretariat

8. **Consideration of Applications for CSLF Membership** CSLF-P-2016-05
   Delegates

9. **Report from CSLF Technical Group**
   Åse Slagtern, Technical Group Chair, Norway

10. **Summary of CSLF Workshop**
    Ryozo Tanaka, RITE, Japan

11. **Summary of Innovation for Cool Earth Forum (ICEF) CCS Session**
    Tim Dixon, IEA Greenhouse Gas R&D Programme (IEAGHG)

12. **Report from CSLF Stakeholders**
    Barry Worthington, United States Energy Association

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10:30-10:45 Refreshment Break

10:45-11:45 Continuation of Meeting

13. Report from the Financing for CCS Projects Task Force
Jarad Daniels, Policy Group Chair, United States

14. Financing CCS
Shannon Cowlin, Asian Development Bank

11:45-13:00 Lunch

13:00-15:15 Continuation of Meeting

15. Report from the Communications Task Force
Stephanie Duran, CSLF Secretariat

16. CSLF Website Launch
Stephanie Duran, CSLF Secretariat

17. Environmental Non-Governmental Organization (ENGO) Perspectives on CCS
John Thompson, Clean Air Task Force

18. Report from the Capacity Building Governing Council
William Christensen, Governing Council Chair, Norway

19. Report from the CSLF Academic Council CSLF-P-2016-06
Sallie Greenberg, Illinois State Geological Survey CSLF-P-2016-07
David Malloy, University of Regina

20. International Energy Agency CCS Activities Update
Tristan Stanley, International Energy Agency

21. Global CCS Institute Update
Alex Zapantis, Global CCS Institute

22. Oil and Gas Climate Initiative Update
Dominique Copin, Total

15:15-15:30 Refreshment Break

15:30-17:15 Continuation of Meeting

23. Upcoming Events (Mission Innovation, Clean Energy Ministerial, COP22)
Jarad Daniels, Policy Group Chair, United States

24. Election of Policy Group Vice Chairs CSLF-P-2016-08
Stephanie Duran, CSLF Secretariat

25. Future CSLF Meetings
Stephanie Duran, CSLF Secretariat

26. Open Discussion and New Business
Delegates

27. Action Items and Next Steps
Stephanie Duran, CSLF Secretariat

28. Closing Remarks / Adjourn
Jarad Daniels, Policy Group Chair, United States

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CSLF-P-2016-03
Revised Draft: 24 August 2016
Prepared by CSLF Secretariat

Draft Minutes of the Policy Group Meeting
London, United Kingdom
Thursday, June 30, 2016

LIST OF ATTENDEES

Policy Group Delegates

Australia:	Paul Trotman, Andrew Barrett
Brazil:	Gustavo Rosas
Canada:	Kathryn Gagnon
European Commission:	Jeroen Schuppers
France:	Bernard Frois, Paul Bonnetblanc
Japan:	Takashi Kawabata, Takuro Okajima
Korea:	Chong Kul Ryu, Chang-Keun Yi
Mexico:	Jazmin Mota
Norway:	William Christensen, Stig Øyvind Uhr Svenningsen
Saudi Arabia:	Hamoud Al-Otaibi (Vice Chair)
South Africa:	Tony Surridge
United Kingdom:	Brian Allison (Vice Chair), Will Lochhead
United States:	Jarad Daniels (Chair)

Representatives of Allied Organizations

Global CCS Institute:	Victor Der, Andrew Purvis
IEA:	Tristan Stanley

CSLF Secretariat

Stephanie Duran, Richard Lynch, Adam Wong, Stephanie Hutson

Invited Speakers

John Gale, IEA Greenhouse Gas R&D Programme
Jon Gibbins, UK Carbon Capture and Storage Research Centre (UKCCSRC)
Tom Howard-Vyse, Communications Consultant
Chris Littlecott, E3G
Scott McDonald, Archer Daniels Midland
Theo Mitchell, Carbon Capture & Storage Association
Philippa Parmiter, Scottish Carbon Capture & Storage
Åse Slagtern, Technical Group Chair, Norway
Keith Whiriskey, The Bellona Foundation
Barry Worthington, United States Energy Association

1. Welcome and Opening Statement

Jarad Daniels, Policy Group Chair, United States, called the meeting to order and thanked the Department of Energy and Climate Change of the United Kingdom for hosting.

2. **Meeting Host's Welcome**
Brian Allison, Department of Energy and Climate Change, United Kingdom, welcomed the attendees and provided the host country remarks.

3. **Introduction of Delegates**
Policy Group delegates introduced themselves. Thirteen of the twenty-five CSLF Members were present, including representatives from Australia, Brazil, Canada, European Commission, France, Japan, Korea, Mexico, Norway, Saudi Arabia, South Africa, the United Kingdom, and the United States.

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

5. **Review and Approval of Minutes from Riyadh Meeting**
The Minutes from the CSLF Policy Group Meeting on November 3, 2015, in Riyadh, Saudi Arabia were approved without change.

6. **Review of Riyadh Meeting Action Items**
Stephanie Duran, CSLF Secretariat, provided a brief summary of the action items from the CSLF Policy Group Meeting on November 3, 2015, in Riyadh, Saudi Arabia. All action items have been completed or are currently in progress.

7. **Outcomes from the 2015 United Nations Climate Change Conference (COP21)**
John Gale, IEA Greenhouse Gas R&D Programme (IEAGHG), spoke on the key outcomes from the 2015 United Nations Climate Change Conference (COP21). At COP21, a truly global agreement was reached by 195 countries to set tough goals and get below the two degree Celsius target. Major economies like the U.S. and U.K. are reducing emissions, while China has announced that emissions will peak before 2030. In order to reach these goals, countries will need a concerted action on low carbon technologies. The establishment of Mission Innovation was another key outcomes from COP21, which will double research and development budgets in participating countries. While CCS was also mentioned in some of the 187 submitted INDCS (representing 94% of global emissions), there is not much interest currently in CCS, especially from developing countries.

   IEAGHG also hosted a side meeting at COP21 that included messaging and participation from groups such as Statoil, Sleipner, SaskPower, and small scale projects in Europe. Over 200 participants, many from developing countries, generated a lot of interests in CCS.

8. **Report from CSLF Technical Group**
Åse Slagtern, Technical Group Chair, Norway, provided a summary of the Technical Group activities. The Technical Roadmap Working Group, chaired by Australia, plans to refresh the Technical Roadmap instead of rewriting it. The plan is for these updates to incorporate the outcomes from COP21, while also modifying time horizons (2020, 2025, 2035), and incorporate new areas such as bio-CCS. The target is to complete the Technical Roadmap in time for the CSLF Ministerial Meeting in 2017. No new projects were proposed for CSLF recognition, and the existing taskforces are all making progress. New taskforces are to be considered at October meeting.

9. Summary of Carbon Capture & Storage Association (CCSA) Workshop
Theo Mitchell, Carbon Capture & Storage Association, provided a summary of the previous day's workshop, hosted by the Carbon Capture & Storage Association (CCSA). The workshop generated great interest and participation, while also covering a variety of topics. There was a particular focus on the importance of commercial value and industrial involvement, with a key aspect of making CCS valuable to business and policy communities. Moving forward, it was agreed that the CSLF has a role to play to engage and put forward a new dialogue on CCS, and to help create a new narrative and re-articulate the argument. The CSLF has been, and needs to continue, to be instrumental in sharing knowledge and leading the way forward.

10. Report from the Communications Task Force
Hamoud Al-Otaibi, Vice Chair, Saudi Arabia, presented an overview of the CSLF Communications Task Force. The task force under the CSLF has engaged the services of a new consultant, to lead the development of a new strategy and several products. Tom Howard-Vyse has experience in public relations in the climate sphere, and provided his perspective on the CSLF and the CSLF website, including messaging, branding, and engagement. There will be a work plan set out between this meeting and the Annual Meeting in October 2016, with the development of several items. The Policy Group chair requested that Mr. Howard-Vyse and the Communications Task Force to flesh out a press kit and core messages policy kit.

11. Report from the Global Collaboration on Large-Scale CCS Projects Task Force
Jarad Daniels, Policy Group Chair, United States, provided an update from the Global Collaboration on Large-Scale CCS Projects Task Force. Having completed the first two phases of its work, the Task Force is now moving on to a new phase 3 initiative. It was proposed, and agreed by the Policy Group, that the Large-Scale Saline Storage Project Network (Network), which was announced at the 2015 CSLF Ministerial Meeting in Riyadh, Saudi Arabia, would also include projects that do not meet the definition of a large-scale integrated CCS projects but are still important potential partners. Current ongoing R&D collaboration under the Network included the Shell Quest project. Potential other opportunities for collaboration include the Illinois Industrial CCS Project, done by Archer Daniels Midland (ADM). Scott McDonald, ADM, spoke on the need to develop confidence with regulators, and that there is an interest in developing technology that aligns with modeling to show conformance, precision, etc. The desire is to utilize and automate technology that can be deployed, and there are advances in various models, with the hope to find less intrusive methods. The Network will proceed with actively seeking partners for the Illinois Industrial CCS projects.

12. Report from the Supporting Development of 2nd and 3rd Generation CCS Technologies Task Force
Kathryn Gagnon, Canada, provided an update from the Supporting Development of 2nd and 3rd Generation CCS Technologies Task Force. This Task Force, led by Canada and Norway, had a goal to help find opportunities to accelerate deployment of second and third generation CCS technologies. The results included a joint study conducted by Canada and Norway, and the findings were presented at the 2015 CSLF Mid-Year Meeting with an executive summary, available on the CSLF website. Conclusions were that there are 30 groupings of emerging technologies, along with 11 test facilities identified around the world. Currently barriers include the lack of market and high costs. The Task Force also provided seven recommendations for consideration by the CSLF

Ministers. Since that meeting, there have been enhanced collaborations and an expansion of the International Test Centre Network. Moving forward, the Task Forces hopes to further enhance networks, expand online tools such as through the development of the CSLF website, enhance research collaboration, and leverage the Mission Innovation mechanism, where 17 of the 21 Mission Innovation countries are also CSLF members.

13. Report from the Financing for CCS Projects Task Force

Bernard Frois, CEA, France, presented on the Financing for CCS Projects Task Force, and highlighted the progress the task force has made in engaging the finance industry, as well as some of the difficulties projects have faced. He provided an update on the task force's events and work plan, and the status of engagement with the finance sector. He emphasized the need for clarity and certainty to encourage investment and interest, and the need for greater advocacy, an area in which the CSLF Secretariat can play a strong role. Ongoing initiatives and key events can be leveraged to encourage greater engagement and progress.

14. Report from the Capacity Building Governing Council

William Christensen, Capacity Building Governing Council Chair, Norway, summarized the status of the CSLF Capacity Building Program. The CSLF Capacity Building Fund was established by the CSLF Ministers at the 2009 CSLF Ministerial in London, and contributions committed total US $2,965,143.75, with donors from Australia (via the Global CCS Institute), Canada, Norway, and the United Kingdom. To date, the Governing Council has approved 19 capacity building projects in 6 countries, with 12 projects completed, 3 projects in progress, 3 projects approved recently at the 29 June 2016 Governing Council Meeting, and 1 project on hold.

The Terms of Reference for the Governing Council was recently revised and is to be revisited for further revisions. Additionally, the Governing Council proposed for the Policy Group to disband the inactive Capacity Building Task Force. The total estimated remaining after accounting for pending and approved projects is AU$1,077,225.23 (exchange rate as of 2 June 2016). The Governing Council welcomes submissions for remaining available funds for CSLF members. The Policy Group approved the Governing Council's recommendation to disband the Capacity Building Task Force.

a. Report from CSLF Capacity Building Event: International Academic CCS Summit

Philippa Parmiter, Scottish Carbon Capture & Storage (SCCS), presented a report from the CSLF Capacity Building Event: International Academic CCS Summit. The SCCS is a partnership of universities, funded by the Scottish Funding Council. SCCS connects research, industry, academia, and other sectors in research that covers full CCS chain and uses, along with externalities. The Summit was funded and supported by U.K.'s Foreign & Commonwealth Office, Natural Resources Canada, and the CSLF Capacity Building Program. The Summit was held in in February 2016, and included 18 research institutes from 10 countries. The main aim of the event was to increase networking, discussions, collaborations, and identify possible funding opportunities from each country. An output report was available, and SCCS would like to follow up on activities with a potential for an international academic network. The objectives of an international academic network would be knowledge sharing and collaboration, and to maximize value from existing injection and storage research, along with pilot facilities.

b. Report from CSLF Capacity Building Event: Offshore Storage Works

Tony Surridge, South Africa, provided a report from CSLF Capacity Building Event: Offshore Storage Works. This international workshop on offshore geologic CO_2 storage was organized by the University of Texas in Austin from April 19-21, 2016. The goal of this workshop was to facilitate sharing of knowledge and experiences, and 13 countries attended, including 7 developing countries. Representatives included experts who currently do offshore storage, including Brazil, Japan, the Netherlands, Norway, and the U.S. Future research opportunities include risk assessment, management, mitigation, and MRV. The meeting also included attendance and some interest from representatives from Nigeria and Ghana. Conclusions reached are that each country is in different place and different stages, but with a common interest. There is a benefit of using depleted oil and gas wells. The workshop recommendations included additional workshops and trainings, a taskforce on infrastructure, and a study on project successes and failures.

15. Report from the CCS in the Academic Council

Jon Gibbins, UK Carbon Capture and Storage Research Centre (UKCCSRC), provided a report from the CCS in the Academic Council, which held a meeting on June 27 at Imperial College. The Academic Task Force agreed to move forward on academic collaboration efforts, with a motivation toward a coordination of effort. The Council has performed a baseline survey, and some initial priority areas have been set up. However, leadership must come from the CSLF Academic Community Task Force. There is a need to leverage and set actions and priorities, and to ultimately finalize a plan of action to present to the Policy Group at the 2016 CSLF Annual Meeting. This action plan will link deliverables and resources, and include primarily recommendations and actions in the next year with a budget to tag on. The Academic Council recommended the need to utilize existing resources and linkages where possible, as the leverage of established connections, programs, and entities will help avoid duplication of efforts to maximize effectiveness of additional resource inputs. The Council will also foster new connections between existing facilities, experts, and sectors, while also streamlining and focusing on best practices. The CSLF can act as a global repository for information and showcase talent and technologies. The main focus of the Council has been on priority areas of training and academic resources, and communications and capacity building.

16. International Energy Agency (IEA) CCS Activities Update

Tristan Stanley, International Energy Agency (IEA), presented on CCS activities within the International Energy Agency, and the need to focus on the recent outcomes from the COP21 Conference in Paris in late 2015. He focused on several areas of potential, including retrofitting of older power plants, negative emissions technologies, BECCS, and the use of hubs and clusters. The IEA is exploring these areas and concepts, and the role CCS will play in a stronger push toward the lower emissions scenarios.

17. Global CCS Institute Update

Andy Purvis, Global CCS Institute, presented on the progress of projects globally, and the priorities for the year ahead. GCCSI will continue its advocacy role, and push for authoritative knowledge sharing. There are several milestones on the horizon, but there is a need to remain focused and become more proactive at the regional level. Political and industrial engagement will also remain important, in both emerging and developed economies. GCCSI is hosting its Annual CCS in Europe Forum in Norway later this year. GCCSI has also produced special reports on Industrial CCS and Hubs and Clusters.

18. CO_2 Market Makers for Strategic European CCS Hubs & Clusters
Keith Whiriskey, from the Bellona Foundation, presented on the need to continue advocating for CCS, and highlighted the role it plays in deeper cuts to emissions following COP21. He focused on the role of hubs and clusters, especially within heavily industrialized parts of Europe such as the Ruhr region and Rotterdam. CCS needs a policy assurance mechanism and a market maker to provide certainty and encourage investment. Industry and government, regionally, nationally, and at the EU level, all need to be engaged to ensure successful deployment. Overall, less time for action remains, as delays have dampened development.

19. Reclaiming CCS in the Public Interest: Perspective from Environmental Non-Governmental Organization (NGO) Community
Chris Littlecott, E3G, highlighted the role of the Environmental NGO community in advocating for CCS. He highlights the delays in development, citing a "lost decade" for the community. Specifically, bad policy and bad luck contributed to an environment that was not conducive for CCS, especially in Europe. CCS needs to be seen as useful beyond coal and fossil fuels, especially its image as an apologist for this sector. It also needs to be recognized as an important part of a decarbonization plan for countries and sectors. He focuses on the challenges that remain for development and deployment globally, highlighting the situation in Europe as an example. Various technologies and developments will play a role in defining success for the industry.

20. Report from CSLF Stakeholders
Barry Worthington, Executive Director of the United States Energy Association, provided a CSLF Stakeholders' Message to the Policy Group. Last year on November 4, 2015 in Riyadh, Saudi Arabia, the Stakeholder's Message reminded the Ministers that our global energy industry is expected to more than double its service to our customers by 2050. This needs to be done with energy production, distribution and utilization being safe, affordable, reliable and clean. Dramatically increased consumers demand will be met by a broad portfolio of resources and technologies, which needs to be accomplished while reducing greenhouse gas emissions, globally by 50% and in OECD countries by 80%. It is clear that we need to attract private capital to CCS & CCUS projects. Supportive government fiscal policies are essential to interest private sector investors. Thus, a message of policy parity for CCS is important. The stakeholders also advocated the importance of supporting the academic community, which supplies much of the human resources and talent needed to support the CSLF mission.

21. CSLF Website Update
Stephanie Duran, CSLF Secretariat, updated the Policy Group on the CSLF website, and provided a request that the Policy Group endorse a Plan of Action for revamping website. These changes would be primarily to the home page, and require a request for action from each member country to updates their profile page. The CSLF Secretariat also requested photos, resources, testimonials, and other items to showcase. There is a desire to tie and link the website to the Global CCS Institute's database. Other changes include a new feature that highlights recent policy and technical developments, along with an upcoming events area that will highlight other meetings. The website will also include a news feed feature, plus drop-down options to explore features, such as events, member pages. The CSLF Secretariat also hopes to update the overview of CCS 101 documents and other items available on the media page.

22. Mission Innovation / Clean Energy Ministerial

Jarad Daniels, Policy Group Chair, United States, provided a summary of the recent Mission Innovation and Clean Energy Ministerial (CEM) Meetings in San Francisco, California, United States. For these events, the CSLF provided papers, including the recent 2015 CSLF Ministerial Meeting Communiqué and an industrial CCS white paper. Many of the countries in attendance at the CEM, checked the box for CCS so it was adequately represented and listed alongside other low carbon options. Some countries are exploring other areas such as net negative emissions technologies and BECCS. The CSLF should continue to engage globally, and the next CEM will be hosted by China.

23. Upcoming Election of Policy Group Vice Chairs

Stephanie Duran, CSLF Secretariat, talked on the upcoming election of Policy Group Vice Chairs, to be held at the 2016 CSLF Annual Meeting. The last election of the Policy Group Chair and Technical Group Chair and Vice Chairs were at the Riyadh meeting in November 2015 for a three-year term through end of 2018. In order to align all leadership roles on the same cycle, it was proposed that the upcoming election of Policy Group Vice Chairs at the 2016 CSLF Annual Meeting will be for a two-year term through the end of 2018. This would bring the elections in sync with the election cycle for the Policy Group Chair and Technical Group Chair and Vice Chairs. The Policy Group approved this change.

24. Future CSLF Meetings

Stephanie Duran, CSLF Secretariat, led the discussion on future CSLF Meetings. Takashi Kawabata, Japan, described the upcoming 2016 CSLF Annual Meeting, to be held in October in Tokyo, Japan. Registration for the meeting is available until September 2, and the meeting will include a site tour of the Tomakomai CCS Demonstration Project, which will begin injection in April 2016.

For future 2017 CSLF Meetings, locations are still to be determined. Keeping in mind the strategy of aiming for a regional balance between meetings, 2017 meetings could take place in Europe and Asia. Jeroen Schuppers, European Commision, offered to gauge possibly hosting the 2017 CSLF Ministerial Meeting in Brussels, as the appetite for CCS and the political situation may improve. As the European Commission will also be hosting CEM in 2018, there is a possibility to dovetail the CSLF Ministerial Meeting with CEM in 2018. However, the negative is that there are no real CCS projects in Belgium for a potential site visit. The CSLF Secretariat agreed to take the action of having conversations and coordinate with members on potential hosts for the 2017 CSLF Meetings. The aim is to have an agenda item on this in time at the 2016 CSLF Annual Meeting.

25. Open Discussion and New Business

No new business was discussed.

26. Action Items and Next Steps

Stephanie Duran, CSLF Secretariat, provided a summary of the day's Policy Group Meeting, and noted the significant agreements and action items. The Policy Group reached a consensus on the following items:

- Moving forward, the Global Collaboration on Large-Scale CCS Projects Task Force will include smaller saline storage projects in the Large-Scale Saline Storage Network, when appropriate, as a subset

- The Capacity Building Task Force has been formally disbanded
- Endorsed the proposal for and planned updates to the CSLF website.
- Agreed on a two-year Vice Chair term for the upcoming Policy Group Vice Chair elections to bring the elections in sync with the election cycle for the Policy Group Chair and Technical Group Chair and Vice Chairs

Action items from the meeting are as follows:

Item	Lead	Action
1	Saudi Arabia, Global CCS Institute, IEA	Under the Communications Task Force, develop a press kit and a detailed communications strategy at the CSLF Annual Meeting to include a schedule for upcoming events, a concept for a TED talk on CCS, and recommendations to improve the CSLF website
2	CSLF Secretariat, Canada	Under Supporting Development of 2nd and 3rd Generation CCS Technologies Task Force, work to explore website functionality in tandem with the CSLF website update
3	CSLF Secretariat	Work with the Capacity Building Governing Council to develop a strategy for providing capacity building to developing countries not currently members of CSLF, including strategies for increasing CSLF membership. Strategy will be presented at the CSLF Annual Meeting.
4	Academic Council	Present a final action plan with concrete recommendations for approval at the 2016 CSLF Annual Meeting
5	CSLF Secretariat	Develop a strategy for how best to engage at COP22 in Morocco and at other upcoming international events and present the strategy at the 2016 CSLF Annual Meeting
6	CSLF Secretariat	Work with CSLF members to find a hosts for the 2017 CSLF Meetings

27. Closing Remarks / Adjourn

Jarad Daniels, Policy Group Chair, 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
www.cslforum.org
CSLF-P-2016-05
27 September 2016

POLICY GROUP

Application of Czech Republic for CSLF Membership

Background

On 26 September 2016, the Czech Republic's Minister of Industry and Trade, the Honorable Jan Mládek, sent a letter to the CSLF Secretariat that requested CSLF Membership for the Czech Republic. The CSLF Terms of Reference and Procedures states that in their letter of application, prospective CSLF 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 Secretariat has reviewed the letter from Minister Mládek and has determined that the Czech Republic has met all of these requirements.

Action Requested

The Policy Group is requested to approve the application for CSLF Membership from the Czech Republic.

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MINISTRY OF INDUSTRY AND TRADE OF THE CZECH REPUBLIC

Jan Mládek
Minister

Prague, September 26 , 2016
No. MPO 51059/16/71300/01000

Dear Honorable Secretary,

As Minister of Industry and Trade of the Czech Republic, I would like to apply for the Czech Republic´s membership in the Carbon Sequestration Leadership Forum (CSLF). The government of the Czech Republic discussed my proposal to apply for the full membership in this important international initiative on April this year and valued broad opportunities associated with the membership in the CSLF especially in terms of strengthening the involvement in international carbon capture & storage partnerships and sharing know how and experience in addition to conduct of technology transfers to the benefit of all stakeholders. The Czech Republic also appreciates the CSLF as an excellent platform to discuss some relevant aspects of the state energy policy, state mineral policy and state climate protection strategy. Let me outline some basic facts to corroborate the eligibility of the Czech Republic for membership in this important international grouping.

Fossil fuels, especially lignite and hard coal still play the important role in the Czech energy sector and the Czech Republic is a significant producer of both of them. The lignite is mined in the Northern-Western part of the Czech Republic and our country is the 4th largest producer of lignite in Europe (following Germany, Poland and Greece) and the 9th largest producer in the world. The total Czech lignite mining production accounted for 38 MT in 2014. Besides that, our country used to be a traditional producer of coking coal in Europe, in spite of the fact that the situation in hard coal industry in Europe is difficult now. The Czech Republic is also very important user of fossil fuels. The Czech energy sector is basically built on domestic reserves of lignite in addition to nuclear energy and gradual increase of using renewable energy sources. The share of electricity produced solely from lignite and hard coal amounted to around 49% in 2015. This suggests a vast potential for using the carbon capture technology in the Czech energy sector.

The issue of climate change has been seriously discussed in the Czech Republic and included in the Policy Statement of the Government of the Czech Republic – "We shall participate in carrying out international measures aimed at curbing climate change. We shall endeavor to negotiate a follow up agreement to the Kyoto protocol with a particular focus on adaptation measures." The role of the carbon capture and storage (CCS) technology in these efforts is more detailed in the State Energy Policy of the Czech Republic approved by the Czech Government in May 2015. The Government of the Czech Republic is aware of the importance of taking measures to mitigate the climate change, and CCS are, in our opinion, essential for the transition to a low carbon economy.

Czech R&D institutions, including but not limited to the Czech Geological Survey, are involved in research, development and demonstration activities in the area of CCS technologies in international scope. This area has also been prioritized within the "areas of interest" of the State Technological Agency of the Czech Republic, namely in the Alfa and Epsilon Programs. The Czech government also encourages the involvement of the private sector in the development and deployment of CCS technologies.

Czech projects and activities associated with the CSLF activities include, among other things, the study of the team of experts headed by Prof. Ing. Mirko Vaněček, DrSc. from the Czech Association of the Economic Geology named "Geological structures that are prospective for CCS technology" and also the R&D project of the Czech Geological Survey „Preparation of the Research Pilot Project on CO_2 Geological storage in the Czech Republic".

Considering the above, I am convinced that the Czech Republic is eligible enough for the membership in the Carbon Sequestration Leadership Forum and I am looking forward to getting an affirmative response from you.

Yours sincerely

Jan Mládek

CSLF Secretariat
U.S. Department of Energy
FE - 27
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MINISTRY OF
INDUSTRY AND TRADE

Carbon Sequestration Leadership Forum
www.cslforum.org

CSLF-P-2016-06
28 July 2016

POLICY GROUP

CCS in the Academic Community:
Academic Council Meeting Readout

Background

At the June 2015 CSLF Mid-Year Meeting in Regina, the CCS in the Academic Community Task force was re-started with a near-term goal of identifying and engaging academic programs on CCS throughout the world. The task force was requested to provide a report summarizing its findings and recommendations, which was delivered at the 6th CSLF Ministerial Meeting in Riyadh.

Members of the task force are Canada, Poland, Saudi Arabia, South Africa, the United Kingdom, the United States, and the Global CCS Institute. A meeting of this council was held at the CSLF Mid-Year Meeting in London on June 27, 2016. This readout is an overview of this meeting, and will provide background to the list of recommendations.

Action Requested

The Policy Group is requested to review the readout of the Academic Council meeting.

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CSLF Mid-Year Meeting

Academic Council Meeting | June 27, 2016

Meeting Notes

Opening remarks and introductions

1. Host welcome
2. CSLF Academic Taskforce Overview
3. Readout from February International Academic Summit: Davey Fitch, Scottish SCCS
    - SCCS is the largest CCS research group in the UK (includes several universities, BGS)
    - Grouping of academia, industry, and government
    - Working to develop variety of international links
    - Publicize jobs/internships, funding opportunities, collaborations
    - Working with industry and public bodies
    - Held International Academic Summit in February 2016 in Edinburgh
        - Funding from NRCan, DECC, and CSLF Capacity Building Fund
        - Event was a forum for academics to progress institutional links in person
        - 18 academic institutes and 130 delegates in attendance
        - Formal MOU signed between University of Edinburgh and SaskPower
        - Produced output report following the meeting
    - Going forward: greater coordination in international funding opportunities, student mobility, and teaching internationalization
    - Goal: worldwide CCS and research network; wide buy-in globally
    - Next steps and actions similar to CSLF goals
    - Conclusions: lots of good will globally but busy academics
    - Someone needs to be responsible to drive it
    - Funding for research helps but better timeline, coordination needed
    - Need to avoid duplication of efforts and making the most of new ways of learning/communicating
    - May be time for an academic network

4. Meeting Expectations and Outcomes: Moderated by Jarad Daniels, U.S. DOE/CSLF Secretariat
    - Value added/relevance of group
    - CSLF is good at engaging on policy—opportunity to coordinate data points and well positioned in global community
    - Where can the Academic Council do the most good? How is it uniquely positioned?
        - Where is there a need/what can be the role?
        - How can we leverage and facilitate existing entities
    - Development of academic materials globally?
    - How do we communicate opportunities, efforts, etc.?
    - Group: come up with deliverables, timelines, responsibilities
        - in time for next meeting—concrete plan (recommendations)
    - important to identify individuals with specialist knowledge and coordinate effectively (may also need to consider funding incentives)
    - Ed Rubin: critical part is financial and other resources
    - There are no easy mechanisms currently for pooling funds

Session 1: Student Training and Practical Learnings on Carbon Capture and Storage

5. Summer Schools and Research Opportunities
   a. Stephen Bryant
   b. Tim Dixon, IEA Greenhouse Gas Programme
      - IEA GHG summer school is well established and well linked
      - Original rationale—shortage of education training in CCS; growing need for expertise and anticipated future employment level; level of student applications; host offers
      - Consistently high level of applications and interest
      - Many host offers, and strong sponsor support
      - Objectives: improve CCS knowledgeable human resource
        - Educate young researchers in all CCS areas, broaden knowledge base, wider context
      - Inspire young researchers to make careers in CCS
        - CCS awareness and global network of peers/contacts
      - Accommodation and course funded by sponsors (travel is not covered)
      - Curriculum: both technical and non-technical aspects
        - Updated throughout the year
      - Group work with topics—research, collaboration, integration
      - Alumni: 461 students from roughly 49 countries; around 25% from developing countries
6. Government Internships and Leadership Development: Mohammad Abu Zahra
      - Masdar Institute in UAE
      - Research university at a graduate level
      - Focus: sustainable technology and clean energy
      - Work in collaboration with MIT
      - Government sponsors scholarships
      - Research and themes: clean energy, water use, sustainability
      - CCUS: area has 10-12 faculty members covering capture, storage monitoring, EOR, policy, and other areas
      - Sponsors and collaboration: some academic institutions, companies
      - Testing and evaluation of CO2 capture and utilization (ESL)
      - Maersk: feasibility study of CCUS integrated, oxy-fuel
      - MIT: core research—development of new sorbents, system
      - Masdar/DOE project: led by RTI group; solid sorbent and suitable processes for post-combustion CO2 capture
      - Other areas include CO2 capture by chemical looping
      - YFEL: Young Future Energy Leaders
        - 1 year program—competitive application, funded
        - Launched in 2009; happens in tandem with Abu Dhabi Sustainability Week every January
        - Students from various majors
        - International students come from IT or STEM courses
        - Local young professionals in related fields
      - CCS program in development as part of YFEL
      - Other aspects: courses, workshops, international events, community service

7. Industry Hands-On Training and Opportunities
    a. Margot Hurlbert, University of Regina: (with input from Mike Monea)
        - Experience with industry with SaskPower
        - Numerous industry partners, collaborations through project
        - New knowledge center set up between BHP Billiton and SaskPower
        - Test facility: will be used as a training center
        - There is a need to resolve issues at the Boundary Dam Project
        - SaskPower: will work with the University of Calgary, bring in academic institutions
        - Water, environment, clean energy research cluster exists
        - Global leadership in CCS and other clean energy activities is a focus
        - 4 of 9 Canadian research chairs work in climate and energy
        - 80 researchers are working in the climate cluster
        - University of Regina is home to a Greenhouse Gas Technology Center
        - Soon: research chair in power engineering will be set up
        - There is a proposed center of excellence in CCUS
            - University of Regina would be a hub of research industries, industry, government, environmental NGOs, communities
        - Vision of the center is to focus on engineering, research, technology development, as well as environmental impact, sustainability, public policy implications
        - Why hands on training? Academics, industry, and students all benefit
    b. Mohamed Pourkashanian, University of Sheffield
        - Experience with the UKCCSRC
        - Focus on education, training, capacity building; aim to invest in highly skilled individuals
        - Universities involved include Cranfield, University of Edinburgh, Imperial College London, Leeds, Nottingham, and Sheffield
        - PACT facilities are involved
        - Specialist national facilities for research and development in advanced fossil energy, bioenergy, and CCS technology; pilot scale platform
        - Aim: support and catalyze industrial work
        - PACT sites/capability; plug and play facilities (ex: carbon capture plant)
        - PACT operational: partnership, collaborations, capacity building and skills
        - Partnership agreements in place
        - Two doctoral training centers—5 academics, 70 partner organizations
        - Also: CPD programs; industry training
        - Education: focus is on post-graduate training
        - Professional development training programs such as short courses, workshops, trainings
        - Development of collaborative training and capacity building in CCS, as well as capacity building and training in CCUS, such as summer schools
        - Aim to involve politicians and acquaint them with the technology
        - PACT is part of the International CCS Test Center Network
        - PACT 2—future capability review
8. Open discussion: Moderated by Vic Der, Global CCS Institute
        - Topics for discussion include effectiveness of student training, learning activities
        - Priority area of emphasis and focus going forward
        - CSLF can serve as a central repository of information

- Is there a need for a more comprehensive program, for example among all summer schools?
- Funding issues—these remain an obstacle
- Strong recommendations will be made to the Policy Group
- We need to leverage existing capabilities and come up with a path forward
- Need commitment to spend time and create an ask for Policy Group ministers
- What are some items worth doing, and what will it take?
- This meeting can help frame this ask, frame a proposal
- Need to prove cost effectiveness and other aspects
- CSLF: can act as a central repository for countries who don't have educational resources
- Government support is critical but academics need to champion this as well
- Is there a role for distance learning? Ex: UK Open University, Future Learning

Session 2: CCS Curriculum and Research Projects Development—Initial Gap Analysis

9. CCS Curriculum Development in Canada: Naoko Ellis, University of British Columbia
    - Multidisciplinary and focused programs, courses can help; also, joint degree programs
    - Example of Canadian program: 3 institutions plus the University of Calgary
        - 6 year course, distance course, 13 week course all exist
        - Various topics available
    - University of British Columbia has a Clean Energy Research Centre and a graduate course on low carbon future
    - Various disciplines are brought together under one course or program
    - Field research station under Carbon Management Canada, other institutions
    - New facility near Vancouver will offer training in this area
    - There are possibilities to leverage technology and academic clusters
    - Need to train, increase public awareness, support for public policy
    - "Ideas to impact"—ties between academia and industry; process of research, translation, and implementation
    - Gap analysis: very sparse; can leverage unique facilities and key institute activities/keep and build connectivity (bi-annual conferences); show a collective face to the world
10. CCS Curriculum Development in the United Kingdom: Colin Snape, University of Nottingham
    - EPSCRC (Engineering and Physical Sciences Research Council) hosts an engineering doctorate center
        - 4 year doctoral program across 2 centers
        - Over 100 doctoral students, 25 industrial partners
    - UK is a focal point for training in the field, with strong inks
    - An advanced skills gap remains
    - Effect of emissions legislation is also involved
    - A large age gap remains among researchers (established professionals versus younger researchers entering the field)
    - There are distinctive features of industrial doctorate center
    - Students are fully engaged with industry
    - Among distribution of projects, 40% go to CCS topics

- CO2 capture, transport, storage, combustion, high temperature materials are all areas covered
- Training module remains varied: largely non-technical covering economic, business, policy aspects
- Public engagement is an ongoing training
- Summer school series exists: focused on the Far East
- Winter schools: this is a joint program with UKCCSRC – more economic
- The University of Nottingham hosts a campus in China
- Currently using CDT model to grow collaborative doctoral training internationally
- Taking broader approach to training—focusing beyond students

11. CCS Research Project Opportunities: Ed Rubin, Carnegie Mellon University
    - History of collaborations, exchanges, and visits
    - Examples of several students who did exchanges as part of exchange/collaboration programs
    - These occurred as a result of several factors:
        - Personal relationships among faculty
        - Mostly on an ad hoc basis
        - Some were institutional programs designed to facilitate and support research collaborations (ex: UKCCSRC)
    - CSLF: not doing as much as it should or could to support these activities
        - Made pitch to CSLF Policy Group at Riyadh meeting
    - CSLF is in a good position to grow these activities
    - Path forward should include identifying and linking academics and researchers with CSLF Technology and Policy Group plans and priorities
    - Determine where and how CSLF and member countries can facilitate international collaborations and opportunities for exchanges that further goals
    - There is a need to assess current funding commitment and mechanisms
12. CCS Research Opportunities in Norway: Arne Graue, University of Bergen
    - Aim to make petroleum activities more sustainable
    - Convert oil and gas industries into more sustainable/cleaner industries
    - Need to increase coordination and collaboration among academics
    - Public interest is there but not informed
    - CCS leaders and researchers need to inform the public, rely on fact-based information
    - Industry also needs to be on board
    - Potential tax credits also need to be considered
    - Norwegian experience—Petroleum School of Norway established; several MOUs exist
    - NorTex Center: Norway and Texas utilizing experience in oil
    - Similar collaborations need to be done on a larger scale
    - CO2-EOR is one way to make a profit
    - Existing infrastructure, on-shore oil fields—these are advantages in Texas
    - Collaboration: among 11 universities in 55 countries with funding
        - This is an example of the way forward
13. Open discussion: Moderated by Mohamed Pourkashanian, University of Sheffield
    - How can we link and integrate activities together?
    - Cost remains an important factor in academia

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- Variation among countries in context and regulation on funding
- Suggestion: have an academic get involved in stakeholder group
- How can CSLF help to expand linkages, communicate out?
- One problem: younger faculty with fewer resources and assistance

Session 3: Communications and Outreach

14. Stakeholders Engagement within the U.S.: Sallie Greenberg, University of Illinois
    - U.S. has the Regional Carbon Sequestration Partnerships—7 regional partnerships
    - Primarily: function of a few organizations and parties
    - Outreach working group has existed since phase 1
    - These partnerships are specifically project based; focused on project based outcome
    - Foundation work—best practices manual
        - A new addition will follow later this year
    - World Resources Institute produced a report on stakeholder engagement
    - Formal engagement processes should start very early in the life of a project
    - RCSP has engagement recommendations
    - What's needed: effective stakeholder guidelines and engagement objectives
    - Activities happen around the who/what/how
    - Stakeholders can be anyone: public, industry, government
    - A project field site or another tangible item is helpful
    - How do you turn a small amount of time into something impactful
    - Engagement process needs to be spread across the project life cycle
    - Uncertainty can be among geologic, sociological factors, others
    - Research question and answer for science and society
    - Similar concerns among industry/researchers, public
    - Recommendations to projects: do your homework, communicate frequently, establish relationships, know audience and topic, be prepared, listen, and respond
    - How do CSLF members interact and participate?
15. Engaging Industry on CCS: David Risk, St. Francis Xavier University
    - Engagement is a limited "market space"
    - Few players, but many requests received
    - Industry gets tired of academics and pitches
    - There need to be mechanisms for alignment and collaboration: brokering, centers, open model
    - Some existing models exist: Carbon Management Canada, PTRC, IEAGHG
    - IEAGHG model: virtual think tank
        - Industry—IEAGHG equals classroom
        - Student: academic research opportunity
        - Researcher: collaborative project
    - Carbon Management Canada model—research provider, broker
        - Industry: gets problems examined/solved
        - Student: semi-embedded in environment
        - Researcher: gets involved in industry; experience
    - PTRC model: strategic research, deployment
        - Industry: builds strategic expertise; learns
        - Student: semi-embedded; management
        - Researcher: deployment of expertise

- Individual partnership is one outcome
- Solo research provider model:
  - Industry: solve a company specific issue
  - Student: embedded research; can commit to project, get mentors, experience, funding
- CSLF model: depends on who, why, and the tie to industry
  - Broker/network role; niche service model; project model

16. Communications through CSLF: Tom Howard-Vyse, CSLF Communications Taskforce
    - Communications experience in climate, energy
    - Worked on communications for Don Valley Project in the UK
    - Aspects of communicating: building expertise, project details, various industry expertise
    - What is the policy climate in 2016? How does government see CCS?
    - How do energy and climate goals sit? For example, in the UK, this will involve Treasury, DECC, and others
    - CCS remains a "political orphan"
      - End of commercialization competition and slashing of the £1 billion fund, questions over government commitment, and recent shake-up of DECC
    - Initial observations on CCS and the CSLF:
    - technology is proven; projects exist and can be visited (in some cases)
    - CSLF brand is not widely known; website needs to be revamped
    - Messages may be without a strategic engagement strategy
    - Context: post-COP21, fossil fuel phase-out, public awareness
    - What can be done? Better public outreach/education, government and policy support
    - Overall: strengths and weaknesses remain, as well as opportunities and threats
    - Shared goals: enhance the CSLF, renew public awareness, strengthen political leadership on CCS, broaden coalition
    - Going forward: finding the right place, time, context, audience
    - Communications strategy: advocacy and strategic engagement
      - Aim to create a virtuous cycle
      - Highlight and establish leadership
    - Messaging strategy: public interest must frame CCS messaging
17. Open discussion: Moderated by Kathryn Gagnon, Natural Resources Canada
    - How can members and the CSLF pool resources?
    - Is there a repository for projects and other useful information?
      - Shared space, one-stop shop
    - How is success defined in the CCS realm? For example, how would a project's success be defined?

Session 4: Academic Community and Capacity Building

18. International Capacity Building Activities: Stuart Haszeldine, Scottish CCS (Absent)
19. Capacity Building in Mexico: Jazmin Mota Nieto, Secretariat de Energia (SENER), Mexico
    - Within capacity building efforts in Mexico, focus is on encouraging involvement in CCS across various sectors
    - Currently preparing for an upcoming pilot project
    - CEMCCUS and CONACYT: collaboration on roadmaps, crafting a strategy with several objectives

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- Plan: UNAM and UC Berkeley are developing a joint masters program
    - Specialized curriculum, exchanges, and projects
- Letter of understanding was signed between the University of Alberta and PTRC: work will cover CCUS research and capacity building in Mexico
    - Drawing on expertise from PTRC at Aquistore and Weyburn Midale
- A memorandum was also signed between Scottish CCS and UNAM
- Continuing to focus on fostering international exchanges
- Capacity building work will require CSLF support, ongoing partnerships and projects, collaborations

20. CSLF Capacity Building Program: Adam Wong, U.S. DOE and CSLF Secretariat
21. Open Discussion: Moderated by Chris Littlecott, E3G
    - Compared to other disciplines, research agendas and issues do not seem to change in CCS
    - Academics have a large role to play in keeping the ball rolling even if other developments have stalled (ex: regulatory, policy)
    - Academics need to show that technology works and show developments on cost reductions to make it competitive
        - Need to show benefits, spillover effects
    - Sharing labs, infrastructure, and facilities could help as part of collaborative activities
        - Research could be made more efficient
    - Expanding definition of capacity building is necessary
    - Expand role of academics to get them involved in pilot projects and offer help for pre-feasibility studies, project development
    - Post-Paris: sustain linkage to deep decarbonization, emission reduction—highlight the role CCS has to play in this
22. Open discussion: entire group
    - Report out to the Policy Group meeting (June 30th) will be given by Jon Gibbins (UKCCSRC)
    - Are these 4 priorities in agenda the right set to focus on?
    - There is some overlap between training and curriculum—sessions 1 and 2 could be combined
    - What are the prospects for online training? Can the Academic Council help to identify and pinpoint online training?
    - The Council should have an ambassador to help ensure capacity and training for carrying out CCS work, projects
    - Aim to utilize the CSLF website to broadcast information, pool resources
    - How can we "embed" students as part of their training?
    - What are the recommendations and asks to the Policy Group?
    - What is the best way to organize this process?
        - Governments have a lot invested already
        - How can we utilize existing facilities, capabilities?
    - 2 sets of recommendations:
        - Small asks that governments can do
        - Larger asks, long term projects
    - Important to keep communications group clued in
        - Important to showcase talent, technologies

- Also important to start work on agreements now—implementing is time-consuming and process can be long
- Will be helpful to put out a call to academics and institutions for their help
- Also aim to make material available (ex: open source, modularized material)
- Many training resources already exist—existing entities and resources should be linked
- There is also the industry connection aspect—how can we create linkages? Look to industry and those who have experience in this field
  - An example is the BHP Billiton/SaskPower Knowledge Centre
- Need to leverage existing summer schools—perhaps focus on creating ones in other countries
- Overall: stick to a flexible and nimble model with fewer restrictions
  - Can be tailored to various areas
- Next steps: what is the best way to move forward?
- Will additional meetings of the Council follow? Ex: CSLF Annual Meeting
- In period before October, will there be additional meetings, webinars?
- How will the group approach the 2017 Ministerial?

Carbon Sequestration Leadership Forum
www.cslforum.org

CSLF-P-2016-07
27 September 2016

POLICY GROUP

CCS in the Academic Community: Key Recommendations on Academic Engagement

Background

At the June 2015 CSLF Mid-Year Meeting in Regina, the CCS in the Academic Community Task force was re-started with a near-term goal of identifying and engaging academic programs on CCS throughout the world.

In June 2016, the Task Force convened the first in-person meeting of the Academic Council on the margins of the CSLF Mid-Year Meeting in London. The meeting focused on four themes identified by the Task Force: Student Training and Practical Learning; Curriculum Development and Gap Analysis; Communications and Outreach; and Capacity Building. Presentations were delivered by representatives from the Academic Council in each of the four thematic areas, and broad discussions on these topics ensued. At the CSLF Policy Group Meeting in London, the group reported on the discussions of the Academic Council meeting and agreed to provide formal recommendations to the CSLF Policy Group at the Annual Meeting in Tokyo in October 2016. This document provides key recommendations for each of the four themes.

Action Requested

The Policy Group is requested to review the Key Recommendations document from the CCS in the Academic Community Task Force.

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Key Recommendations on CSLF Academic Engagement

Report by the CSLF Academic Task Force

October 2016

I. Background

The academic community plays a vital role to advance carbon capture and storage (CCS) technologies[1] through research, development, and demonstration (RD&D), as well as through policy guidance and a wide range of educational programs that support development of the next generation of scientists, engineers and policymakers. Governments can strongly influence the extent to which the academic community is engaged in CCS. The Carbon Sequestration Leadership Forum (CSLF) is in a unique position to catalyze, grow and strengthen the academic community's contribution to achieving CSLF goals.

The mission of the *CCS in the Academic Community Task Force* (Academic Task Force), originally established in 2008, is to identify and engage academic programs on CCS throughout the world to help support the mission and path forward for the CSLF. Early accomplishments of the Task Force included a mapping and gap analysis of CCS post-graduate academic courses worldwide and links to the CSLF Capacity Building Task Force. Although in recent years this Task Force has been dormant, at the CSLF Mid-Year Policy Committee Meeting in Regina, Saskatchewan, Canada in June 2015, it was re-established with a new organizational structure and focus– to foster and support the CSLF mission and objectives via academic CCS research programs, international collaborations, research exchanges, networks, and summer schools. With more proactive engagement among the CCS academic community, the CSLF can facilitate international research collaborations in priority areas and leverage funding opportunities that advance the CSLF mission.

At the 2015 CSLF Ministerial, the Academic Task Force presented a *Baseline Survey and Plan of Action: Mechanisms for International Collaborations, Key Research Groups, Summer Schools and Networks* (Appendix 1) and secured endorsement from CSLF Ministers on the importance of the CCS academic community to help meet CSLF goals.

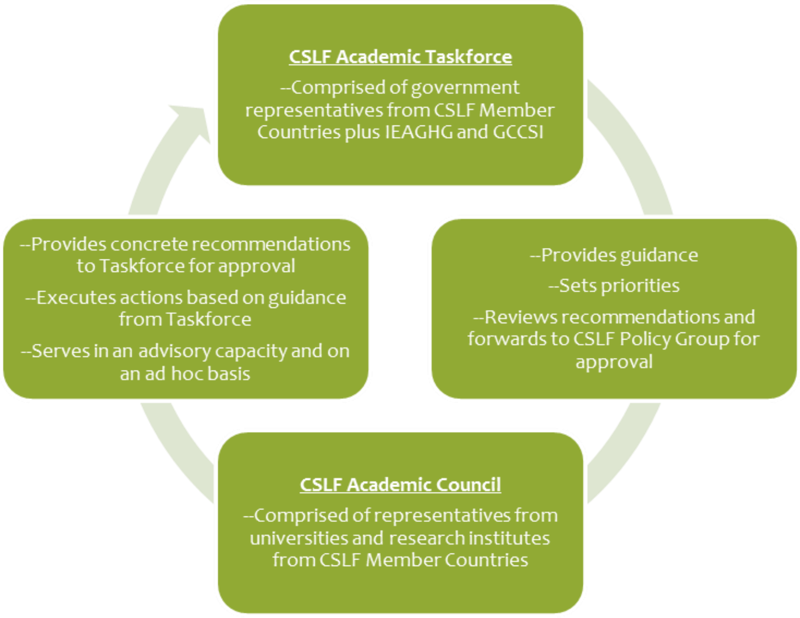
Following the Ministerial, the Academic Task Force established an Academic Council, comprised of representatives from institutes and universities in CSLF Member Countries, to serve in an advisory capacity to the Task Force, providing

[1] CCS by definition includes carbon capture, utilization, and storage.

recommendations and acting on guidance received. The Task Force identified an initial set of priority areas for discussion with the Academic Council.

In June 2016, the CSLF Academic Task Force convened the first in-person meeting of the Academic Council on the margins of the CSLF Mid-Year Meeting in London. The meeting focused on four themes identified by the Task Force: Student Training and Practical Learning; Curriculum Development and Gap Analysis; Communications and Outreach; and Capacity Building. Presentations were delivered by representatives from the Academic Council in each of the four thematic areas, and broad discussions on these topics ensued. At the CSLF Policy Group Meeting in London, the group reported on the discussions of the Academic Council meeting and agreed to provide formal recommendations to the CSLF Policy Group at the Annual Meeting in Tokyo in October 2016.

<u>Structure</u>



II. Key Actions and Recommendations

In Task Force discussions following the Academic Council meeting, the group agreed to combine two themes and concentrate recommendations on: Student Training, Practical Learning, and Curriculum Development; Communications and Outreach; and Academic Community and Capacity Building.

Theme 1: Student Training, Practical Learning and Curriculum Development

Description: With the trending of Massive Open Online Courses and open access materials, accessibility to education has advanced and become enriched. While these types of technical platforms exist, there is not a clear grasp of what is available amongst the academics and industrial sectors of the CSLF Member Countries on materials for CCS training and curricula. This is an area academics can contribute in educating researchers, academics, industry and the public through sharing resources. Furthermore, well-organized, accessible resources can be leveraged towards capacity building in disseminating concepts, theory, and case studies in building the knowledge foundation in the CCS area. For example, the Province of British Columbia (B.C.) in Canada implemented the *B.C. Open Textbook Project* to increase access to higher education for students by providing openly licensed textbooks. This project focused on textbooks used in the top 40 highest-enrolled subject areas, with additions that followed. Projects such as these could offer CCS academics and programs to share resources more effectively, allowing students to access a wider selection of educational materials.

Thematic Goals

- *Organize course and curriculum on CCS for better exposure.*
- *Build a community of CCS educators.*
- *Create a network of CCS academics on the CSLF platform.*
- *Cultivate a community of educators in CCS through material sharing and regular meetings.*
- *More broadly publicize internship opportunities.*
- *Broaden opportunities for students in an international setting.*
- *Create a repository of material aimed at post-secondary education and professional training.*

In addition, CSLF nations can help to promote a forward thinking environment for CCS to grow by developing a framework for graduates in CCS related studies to spend time with appropriate government policy departments. Organizing and publicizing these can help to grow this sector internationally. Some internship programs may have citizenship, education, or age guidelines. There are several examples of existing internship programs that might be expanded or replicated in other countries. For example, the European Commission offers graduate traineeships across its whole remit (including energy and environment), and the International Energy Agency offers some internships to post-graduate students, which are managed through the Organisation for Economic Cooperation and Development. Additionally, the National School of Public Administration of Poland offers six-week internships for its students, including internships in other government agencies; the U.S. Department of Energy has hosted three Polish interns over the past three years, providing exposure to U.S. policy and technical perspectives on CCS. Masdar Institute in the United Arab Emirates hosts the Young Future Energy Leaders Program, which seeks to educate, inspire, and position students and young professionals to become future leaders in the fields of alternative energy, by connecting them with today's leaders, offering internships and research opportunities, and facilitating energy-related site visits. The United Kingdom Parliamentary Office of Science and Technology and the Scottish Parliament Information Centre offer 3-month placements for Research Council UK (RCUK)-funded Ph.D. students and shorter internships for MSc students. Finally, many non-governmental organizations active in the energy-climate space host internships; two of the most high profile opportunities with some track record on CCS include Chatham House (United Kingdom), which has a large energy and climate program, and the World Resources Institute (United States and internationally). These programs could be models for other countries to consider and/or provide opportunities for international collaboration.

Additionally, providing students with opportunities for hands-on learning at CCS projects can enrich student learning and help build expertise in CCS. For example, the Mitacs Globalink Research Internship funds student research exchanges with an industrial focus (inwards and outwards) and accepts students on a rolling call. In addition, University of Regina has agreements with University of Edinburgh, University of Texas, Imperial College London, and University of Melbourne, which enable competitive internships for graduates from these universities at SaskPower. These programs, too, could be expanded or replicated to provide opportunities for students from around the world that are interested in pursuing careers in the CCS industry.

Recommendations:

- Update *Baseline Survey and Plan of Action* to include input from ALL CSLF Member Countries prior to the 2017 CSLF Mid-Year Meeting.
- Conduct a gap analysis on CCS post-graduate course mapping and summer school programs, leveraging ongoing work under the Trilateral CCS Initiative (Canada, Mexico, and the United States).[2]
- Identify existing modularized content for CCS knowledge sharing and education for broad dissemination and develop new modularized content, as needed.[3]

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[2] The University of Regina has offered to fund $7-10K for a graduate student to conduct the gap analysis.
[3] The University of Calgary is working on a CCS course, and the University of Regina has a non-credit course on CCS that may be applicable. Carbon Management Canada (CMC) may also have training modules. The Academic Council will need to address licensing issues and the extent to which these entities are willing to share the training course materials. This may require setting up a system to allow content developers to collaborate through licensing (e.g., creative commons).

- Request CSLF Member Countries identify existing internships with applicability to CCS and provide information to the Secretariat prior to the 2017 CSLF Mid-Year Meeting.
- Request CSLF Member Countries' government organizations consider hosting interns to expose them to CCS policy and technical perspectives of the respective countries.
- Request CSLF stakeholder community to identify internship opportunities, with an emphasis on exposure to and/or hands-on experience at operational CCS sites.

Theme 2: Communications and Outreach

Thematic Goals

- *Broadly disseminate CCS activities and opportunities for the academic community.*
- *Create and maintain momentum through virtual meetings.*
- *Host public scholarship forum and activities.*
- *Broad publication of international student research*

Description: Postgraduate opportunities are currently piecemeal, and are often not well communicated outside of national or regional boundaries. While efforts to collaborate internationally are underway (e.g., Scottish CCS (SCCS) with Canada, University of California at Berkeley with the National Autonomous University of Mexico (UNAM)), there is not a 'one-stop' resource for storing and advertising postgraduate academic opportunities around the world. Developing such a collaborative resource should see an increase in the level of collaboration, as contributors are kept up to date with active research in foreign institutes. In addition, ideally this would also lead to a greater degree of securing international collaborative funding for postgraduate studentships.

Additionally, several countries and regions have specific funding for industry, universities and research institutes to collaborate internationally. At times though, these programs would have greater impact if there was a way to synchronize and leverage available funding. By gathering and hosting these on the CSLF website, this would increase visibility for this type of funding, and encourage funding bodies to better synchronize suitable funding calls. Some examples of current student-focused funding announcements are included in Appendix 3.

Recommendations:

- Build website page under CSLF website on academic resources that includes links to:
    - outreach programs;
    - internship opportunity announcements;
    - summer schools and training programs on CCS;

- webinar announcements; and
- CCS modularized training.[4]

- Task and fund, where necessary, the Academic Council to identify and create content for website.
- Post videos from CSLF meetings and CCS workshops, in addition to relevant course materials for the meetings and workshops.
- Request CSLF Member Countries to provide information on their international funding opportunities for publication and broad dissemination via CSLF website on a routine basis.
- Request CSLF Member Countries' identify a point of contact for country-specific updates to the website.
- Post student research on CCS on the CSLF website.
- Enable academics to register as an academic (instead of a stakeholder) on the CSLF website.
- Fund an annual academics event based on *International CCS Academic Summit*.[5]

[4] The CSLF Secretariat will need to consider how best to maintain the academic resources webpage as content may require routine updates.

[5] The Academic Council should also seek to leverage Scottish CCS's extensive network, where possible.

Theme 3: Academic Community and Capacity Building

Description: CSLF Member Countries are leaders in CCS, and many are home to a variety of academic institutions, research and development, and industry. Several countries are also host to demonstrations, projects, and fully operational plants that showcase CCS technologies. For members of the public, these sites are examples of CCS in action. For researchers, academics, and industry, these sites offer the chance to observe and learn. Study tours of project sites and plants are a valuable resource where visitors can learn directly from plant operator and take this knowledge with them.

Thematic Goals

- *Create learning opportunities for those unfamiliar with CCS.*
- *Improve outreach, awareness, and capacity building on CCS.*
- *Serve as a resource for capacity building activities and support the CSLF Capacity Building Programme, where relevant.*
- *Broad publication of international student research.*
- *Begin stakeholder engagement early and make public engagement a priority.*
- *Integrate stakeholder engagement into project management and regulatory processes.*
- *Build long-term stakeholder relationships.*
- *Make sufficient investment in time and resources.*
- *Understand and consult community.*
- *Maintain flexibility and diligence.*

These tours would be especially beneficial for delegations or visitors from developing countries who may not have first-hand experience with CCS experts or projects. For those countries that are new to CCS or looking for ways to incorporate it into their energy and environmental portfolios, study tours can offer first-hand and practical knowledge and complement other capacity building efforts.

This is an area where the academic community can assist through organization and engagement efforts, as many host country academics will have ties with projects and plants. They may also be able to leverage academic networks, institutions, and resources that can facilitate these study tours for visitors. Study tours can be a helpful learning opportunity for those unfamiliar with CCS, especially those who may not have much exposure or access to the technology. Developing countries can benefit from these tours, as they offer tangible examples of the technology at work. With input and engagement from academics, industry professionals, and plant operators, study tours can act as a tool for outreach, awareness, and capacity building.

There are multiple countries that currently offer study tours on CCS. Australia has hosted various tours at power plants where CCS technologies are tested or used commercially, at projects such as Otway, and at research laboratories. Norway is home to established projects, such as the Sleipner CO2 project, in operation since 1996, and ongoing research facilities such as the Technology Center Mongstad. The U.S. Research Experience in Carbon Sequestration (RECS) is a 10-day program offered to graduate and doctoral students and early career professionals that includes classroom instruction and site visits. Site visits have included the National Carbon Capture Center, Plant Barry, and Kemper County Energy Facility. Located in Canada, the Boundary Dam Integrated CCS Project is the world's first commercial CCS project at a coal-fired power plant. Its operator, SaskPower, has created The Knowledge Center, through BHP Billiton's support of $20 million over five years. This center aims to accelerate global CCS deployment by allowing the learnings acquired at Boundary Dam to be shared broadly, bringing down the costs of CCS, and managing development risk. Details on Canadian study tours are included in Appendix 4.

Stakeholder engagement is also widely recognized as a critical piece of the CCS value chain. Stakeholder engagement can be defined as a multi-directional process that brings together interested and impacted parties to discuss and implement activities that will potentially impact or influence the lives of a particular group of stakeholders. Indeed, a lack of stakeholder engagement, public awareness, and public support are often cited as major barriers to the development and implementation CCS projects and policy. At present, many CCS demonstration projects are conducted through partnerships between government, industry, non-governmental organizations, and academia. Demonstration projects and commercial projects coming online have several stakeholder groups, including general public, educators, government, regulators, industry, landowners, farmers, and others depending on specific circumstances. Each stakeholder may have varying interests, information needs, or concerns that need to be acknowledged and addressed. Additional detail is provided in Appendix 5.

Recommendations:

- Work with Capacity Building Governing Council on recommendations for capacity building moving forward.
- Request CSLF Member Countries to consider hosting study tours for developing countries (potentially outside of CSLF membership) with engagement and organization by the academic community.
- Evaluate CSLF Academic Council hosted webinars via CSLF for capacity building.
- Develop stakeholders' guidelines and engagement objectives document for use by CSLF Member Countries' Stakeholders.
- Create, evaluate, and refine stakeholder engagement strategy and communications plan.

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CSLF-P-2016-08
29 August 2016

POLICY GROUP

Election of Policy Group Vice Chairs

Background

As stated in Section 3.3 (a) of the CSLF Terms of Reference and Procedures, CSLF Chairs and Vice Chairs will be elected every three years. The previous election of the Policy Group Vice Chairs was at the Washington meeting in October 2013, so the next election is scheduled for the Policy Group Meeting on October 7, 2016 in Tokyo, Japan.

Action Requested

The Policy Group is requested to hold an election to select three Vice Chairs whose term will run through November 2018. (*Note: This one-time two year cycle will align the terms of the Vice Chairs with that of the Policy Group Chair*.)

Election of Policy Group Vice Chairs

At its meeting in Paris in 2007, the Policy Group reached consensus on the following procedures for election of all CSLF Chairs and Vice Chairs:

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.*

At the Policy Group meeting in London on June 30, consensus was reached that the current election of Vice Chairs would be for a two year period (for this election cycle only), in order to align with the Policy Group Chair's election cycle.

On 1 August 2016, the Secretariat sent an e-mail to CSLF Policy Group delegates, informing them of the upcoming election of the Policy Vice Chairs, and that nominations must be received by the Secretariat no later than six weeks prior to the meeting (i.e., by 26 August 2016.)

The following nominations were received by the Secretariat:

- The European Commission has nominated China, Saudi Arabia, and the United Kingdom to continue in their roles as Policy Group Vice Chairs.
- This nomination has been supported by Australia and Norway.

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Carbon Sequestration Leadership Forum
www.cslforum.org

CSLF-T-2016-05
Revised Draft: 11 August 2016
Prepared by CSLF Secretariat

DRAFT

Minutes of the Technical Group Meeting

London, United Kingdom
Tuesday, 28 June 2016

LIST OF ATTENDEES

Chair	Åse Slagtern (Norway)

Delegates

Australia:	Andrew Barrett (*Vice Chair*), Max Watson
Canada:	Eddy Chui (*Vice Chair*), Michael Monea
European Commission:	Jeroen Schuppers
France:	Didier Bonijoly, David Savary
Germany:	Jürgen-Friedrich Hake
Italy:	Paolo Deiana
Japan:	Ryozo Tanaka, Takeshi Kawabata
Korea:	Chang Keun Yi, Chong Kul Ryu
Mexico:	Jazmín Mota
Netherlands:	Paul Ramsak
Norway:	Jostein Dahl Karlsen, Lars Ingolf Eide
Poland:	Mateusz Głogowski
Saudi Arabia:	Hamoud AlOtaibi, Ahmed AlEidan
South Africa:	Tony Surridge (*Vice Chair*)
United Kingdom:	Brian Allison, Eva Stepniewska
United States:	Mark Ackiewicz

Representatives of Allied Organizations

Global CCS Institute:	Andrew Purvis, Victor Der
IEA:	Tristan Stanley
IEAGHG:	Tim Dixon, James Craig, Jasmin Kemper

CSLF Secretariat	Richard Lynch, Adam Wong, Stephanie Duran, Stephanie Hutson

Invited Speakers

Australia:	Max Watson, Program Manager - CO_2 Storage, CO2CRC
United Kingdom:	Steve Widdicombe, Strategic Sciences Lead, Marine Ecology and Biodiversity Section, Plymouth Marine Laboratory

Observers

Australia:	Paul Trotman*
Canada:	Naoko Ellis, Kathryn Gagnon*, Christine Lazaruk, Simon O'Brien, Jeremy Rayner
Czech Republic:	Pavel Kavina
Japan:	Kimiko Nakanishi, Takuro Okajima*
Norway:	Mohsen Assadi, Britta Paasch, Olav Skalmaraas
Saudi Arabia:	Wolfgang Heidug
United Kingdom:	Bruce Adderley, Mark Crombie, Jon Gibbins, M. Pourkashanian, Cosimo Sbano, Matt Wills
United States:	Jarad Daniels*, Bill Elliott, Amishi Kumar, Scott McDonald, Ed Rubin, Judd Swift

* CSLF Policy Group delegate

1. Chairman's Welcome and Opening Remarks

The Chairman of the Technical Group, Åse Slagtern, called the meeting to order and welcomed the delegates and observers to London. Ms. Slagtern mentioning that this would be a busy meeting, with updates from several task forces as well as the working group that is updating the CSLF Technology Roadmap. In addition there would be discussion on possible future Technical Group activities.

Ms. Slagtern also mentioned that the current meeting would be, as usual, very content-rich, with many items of interest to attendees. This includes presentations on the CSLF-recognized CO2CRC Otway Project and on CCS in the United Kingdom, a report on a sub-seabed controlled release experiment by the United Kingdom's Plymouth Marine Laboratory, and several presentations by the IEA Greenhouse Gas R&D Programme (IEAGHG).

2. Meeting Host's Welcome

Brian Allison, representing the United Kingdom's Department of Energy and Climate Change (DECC) [since 16 July 2016 the Department of Business, Energy and Industrial Strategy (DBEIS)], welcomed the meeting attendees to London. Mr. Allison thanked the sponsors for the four-day meeting and hoped that meeting attendees would have a pleasant stay in London.

3. Introduction of Delegates

Technical Group delegates present for the meeting introduced themselves. Sixteen of the twenty-five CSLF Members were represented. Observers from eight countries were also present.

4. Adoption of Agenda

The Agenda was adopted with the addition of short talks, near the end of the meeting, from the Global Carbon Capture and Storage Institute's Andrew Purvis, and from Wolfgang Heidug about methodology for the United Nations Framework Classification for carbon capture and storage (CCS).

5. Approval of Minutes from Riyadh Meeting

The Minutes from the November 2015 Technical Group Meeting in Riyadh, Saudi Arabia were approved with no changes.

6. Report from CSLF Secretariat

Richard Lynch provided a report from the CSLF Secretariat which covered the status of action items from the November 2015 Technical Group Meeting and some of the highlights from the overall Ministerial Meeting. This was a five-day event, including the Conference of Ministers and the Ministers' site visit to Saudi Aramco's Dhahran Facility.

Mr. Lynch summarized some of the key actions identified by CSLF Ministers that were needed to accelerate large-scale deployment of CCS. These included advocating for clean energy policies that support CCS alongside other clean energy technologies, fostering international collaboration for large-scale CCS projects, removing barriers for private sector investment in CCS, giving CCS fair consideration in clean energy policies while supporting development of comprehensive CCS policy frameworks, supporting industrial CCS applications, and continuing to explore the potential of CO_2 utilization technology. Highlights from the overall Ministerial Meeting included CSLF recognition of five projects (see below) and presentation of CSLF Global Achievement Awards to three completed CSLF-recognized projects (the CO_2 Capture Project Phase 3, the CO2CRC Otway Project Stage 1, and the CGS Europe Project). And also, the CSLF is now larger, with the addition of Romania and Serbia as new members.

Mr. Lynch stated that there were five Action Items from the November 2015 meeting, four of which are now complete. Still pending is a request for the IEAGHG to determine a way to allow access to a journal paper that is also the final report from the CSLF Task Force on CO_2 Storage Efficiency in Deep Saline Aquifers. Tim Dixon responded that the journal containing the report was published by Elsevier and that it could not be freely downloaded. Mr. Dixon offered that instead, the Technical Group use the presentation from the Task Force Chair at the June 2015 CSLF Meeting as the final report. The Technical Group accepted this suggestion.

Mr. Lynch closed his presentation by summarizing the outcomes from the Riyadh Technical Group Meeting:

- Five projects were recommended by the Technical Group to the Policy Group for CSLF recognition.
  - CO_2 Capture Project Phase 4
  - CO2CRC Otway Project Stage 2
  - Oxy-Combustion of Heavy Liquid Fuels Project
  - Carbon Capture and Utilization Project / CO_2 Network Project
  - Dry Solid Sorbent CO_2 Capture Project
- The Technical Group formed a new Task Force on Offshore CO_2-EOR.
- The Technical Group formed a new Task Force on Bioenergy with CCS
- The Technical Group formed a new Task Force on Improved Pore Space Utilisation.
- The Technical Group temporarily postponed decisions on forming other new task forces.

7. Overview of CCS Activities in the United Kingdom

Eva Stepniewska, representing DECC, briefed the Technical Group on policy developments in the United Kingdom related to CCS. She stated that the cancellation of the two large-scale CCS projects, Peterhead and White Rose, should not be taken as a sign that the United Kingdom has written off CCS. Instead, there are a range of options being considered that would move CCS forward. These include developing an action plan for industrial CCS, supporting the development of new technologies, and knowledge transfer of key learnings from Peterhead and White Rose. Ms. Stepniewska also stated that there are several policy questions to be addressed as the United Kingdom considers its options in regards to CCS, concerning CO_2 transport infrastructure and its cost, industrial CCS, creating markets for CO_2 to aid CO_2 utilization, innovation and its role in reducing the overall cost of CCS, and what can be learned from other countries which are engaged in large-scale CCS.

Brian Allison then gave a presentation about the various CCS technical developments being supported by the United Kingdom Government. The CO_2 Storage Appraisal Project is bringing to maturity a portfolio of five storage sites and will thus simplify commercial discussions toward CO_2 geologic storage. Mr. Allison stated that the five sites selected are all offshore sub-seabed and are geographically and technically diverse (including deep saline aquifers and depleted oil and gas fields). In all, the five sites within the selected portfolio represent a total of 1.6 gigatonnes (GT) storage. A key finding of the project has been that the national offshore sub-seabed storage resource is upwards of 75 GT, key components of which can be brought into service readiness without extensive appraisal programs.

Four other United Kingdom Government-supported initiatives were briefly described by Mr. Allison. The Boulby Underground Laboratory, located 1100 meters below ground on the northeast coast of England, has been home for the investigation into use of cosmic ray muon detection technology for deep geological monitoring of CO_2 within a storage site. Carbon Clean Solutions, whose United Kingdom office is located in the city of Reading, is developing a low cost energy efficient solvent-based technology for separating CO_2 from flue gas of power plants and industrial utilities. C-Capture, located in the city of Leeds, is developing a low-energy approach for removal of CO_2 from methane gas streams, in particular biogas from anaerobic processes and landfills. The United Kingdom Government has also worked with the Scottish Government to provide an early stage R&D grant totaling £4.2 million to Summit Power to help advance the proposed Caledonia Clean Energy Project, to be located at the city of Grangemouth. This project would be based on coal gasification, generating 570 megawatts (net) of electricity with 90% CO_2 capture. This would be the first carbon capture power plant designed to compress and deliver CO_2 at intermediate rather than high pressure.

Mr. Allison closed his presentation by briefly describing the European "Accelerating CCS Technologies" (ACT) initiative for funding CCS-related RD&D innovation across the ACT partnership (e.g., Norway, Germany, the Netherlands, Switzerland, Spain, and the United Kingdom). The goal of the initiative is to "facilitate the emergence of CCS via transnational funding aimed at accelerating and maturing CCS technology through targeted innovation and research activities". The United Kingdom Government has contributed £5.5 million to a fund currently totaling nearly £42 million. The initiative is beginning in 2016, and successful projects will run for a maximum of three years. A transnational call for proposals was issued in early June, and each country involved will fund its own partners. Details of the call, managed by the Norwegian Research Council and the ACT partners, can be found at the ACT website (http://www.act-ccs.eu/).

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

Tim Dixon gave a presentation about the IEAGHG and its continuing collaboration with the CSLF's Technical Group. The IEAGHG was founded in 1991 with the mission to provide information about the role of technology in reducing greenhouse gas emissions from use of fossil fuels. The focus is on CCS, and the goal of the organization is to produce information that is objective, trustworthy, and independent, while also being policy relevant but not policy prescriptive. The "flagship" activities of the IEAGHG are the technical studies and reports it publishes on all aspects of CCS, the eight international research networks about various topics related to CCS, and the biennial GHGT conferences, the next one in November 2016 in Lausanne, Switzerland. Other IEAGHG activities include its annual International CCS Summer School, peer reviews with other organizations, activity in international regulatory organizations such as the ISO and the London Convention, and collaboration with other organizations, including the CSLF.

Mr. Dixon mentioned that since 2008 the IEAGHG and CSLF Technical Group have enjoyed a mutually beneficial relationship which allows each organization to cooperatively participate in the other's activities. This has included mutual representation of each at CSLF Technical Group and IEAGHG Executive Committee (ExCo) meetings, and also the opportunity for the Technical Group to propose studies to be undertaken by the IEAGHG. These, along with proposals from IEAGHG ExCo members, go through a selection process at semiannual ExCo meetings. So far there have been four IEAGHG 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), "Potential Implications of Gas Production from Shales and Coal for CO_2 Geological Storage" (November 2013), and "Life Cycle Assessment of Carbon Capture, Utilization and Storage (CCUS) – Benchmarking". For the current year, the IEAGHG has already published eight new reports with many other studies underway or awaiting start that will eventually lead to other reports.

Mr. Dixon closed his presentation with a short description of outcomes from the 2015 COP21 meeting in Paris. Article 2 of the COP21 Agreement states that the purpose of the agreement is to limit global warming to "well below" 2.0 degrees C (by the year 2100) and to pursue 1.5 degrees C. Articles 3 and 4 of the agreement indicate that developed countries should take the lead toward this goal, and to update their Nationally Determined Contributions (NDCs) every five years. Other articles in the COP21 Agreement concern cooperative approaches, finance, technology development, capacity building, education, and transparency. Mr. Dixon stated that the International Panel on Climate Change (IPCC) will be examining the 1.5 degrees C scenarios and will issue a special report by the year 2018. For the 2.0 degrees C scenario, CCS will enable access to significant quantities of fossil fuels that would otherwise have to remain unburnable.

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

The PIRT Chair, Andrew Barrett, gave a short presentation which summarized PIRT activities and the previous day's meeting. The PIRT is currently involved in four main activities: reviewing projects nominated for CSLF recognition (however, there were none for this meeting), updating the CSLF Technology Roadmap (reported in the next item), organizing technical workshops for future CSLF meetings, and finding ways to better engage sponsors of CSLF-recognized projects. Mr. Barrett stated that much of the PIRT meeting was taken up by discussion of the fourth activity, with two resulting action items:

- The CSLF Secretariat, working with the sponsor of the Illinois Basin – Decatur Project, will develop a useful format for CSLF-recognized projects to report their status.
- PIRT delegates from Australia, Canada, and the United States will use the new project reporting format to engage projects located in their countries (approx. 4-8 projects in total) and prepare short status summaries in time for the 2016 CSLF Annual Meeting.

Concerning technical workshops, there was one other action item: the Secretariat and the PIRT delegate from Japan (Ryozo Tanaka) will develop a structure for a technical workshop to be organized as part of the upcoming CSLF Annual Meeting. Japan's delegation will have the overall ownership of the event, including inviting participants.

10. Progress Report on next CSLF Technology Roadmap (TRM)

The Chair of the TRM working group, Andrew Barrett, gave a short progress report presentation about the 2017 TRM. The TRM working group had been formed at the 2015 Technical Group meeting in Riyadh with the mandate to produce a new TRM in time for the anticipated Ministerial Meeting near the end of 2017. The process chosen for the rewrite was to use the 2013 TRM as a basis and refresh its content as needed. Mr. Barrett stated that there have been three teleconferences of the working group and that the current focus was on Section 4, "Technical Needs".

At the previous day's PIRT meeting, there had been consensus that the timeline for the rewrite should be advanced so that a final draft would be complete in time for the 2017 Mid-Year Meeting. There was also consensus that outcomes from the COP21 meeting should be incorporated as should technologies such as bioenergy with CCS that were only briefly mentioned in the 2013 TRM. To assist in the rewrite process, the working group will create a "technical needs" survey for obtaining pertinent information from existing projects.

11. Report from Offshore CO_2-EOR Task Force

Task Force Chair Lars Ingolf Eide gave a brief update on the task force, which was established at the November 2015 meeting in Riyadh. The purpose of the task force is to highlight differences and issues between onshore and offshore CO_2-EOR as well as offshore CO_2-EOR and pure offshore CO2 storage. The task force will also highlight any technical solutions which benefit both pure offshore CO_2 storage and offshore CO_2-EOR.

Mr. Eide stated that the task force has held one preliminary meeting, in April in the United States. The task force timeline calls for completion of the first draft of the final report in time for the 2017 CSLF Mid-Year Meeting and a finalized report, as well as findings and conclusions, at the 2017 CSLF Ministerial Meeting. The contents of the report will include sections on the current status and future potential for offshore CO_2-EOR, a summary of emerging technical solutions for offshore CO_2 storage and EOR, descriptions of potential CO_2 supply chain issues and infrastructure needs, a description of regulatory requirements for offshore CO_2 utilization and storage, and recommendations for overcoming any barriers to accomplishing offshore projects. Mr. Eide stated that current task force members include Norway (as chair), Brazil, Canada, the United States, and the IEAGHG, and that more participation from other CSLF members and outside organizations would be welcome.

12. Report from Bioenergy with CCS (BECCS) Task Force

Task Force Chair Mark Ackiewicz gave a brief update on the task force, which was established at the November 2015 meeting in Riyadh. The focus of the task force is to identify and summarize global efforts, successes, and challenges to deployment for BECCS. Current task force members include the United States (as chair), Italy, Norway, and the IEAGHG. Others expressing interest in either joining the task force or providing input for the task force's final report included the Netherlands, the European Commission, and the United Kingdom. Mr. Ackiewicz stated that a technical focus of the task force would be to look at the unique challenges for CO_2 capture technologies to be deployed at bio-power, biofuels, and other bio-industry facilities. This would include both current projects and also business cases for possible future projects – the task force will summarize current finding and identify any technology gaps. The list of projects to be examined by the task force is not yet final, but will include the ADM ethanol facility in the United States and the Klemetsrud waste-to-energy facility in Norway.

Mr. Ackiewicz provided the timeline for the task force. There will be a status update at the 2016 CSLF Annual Meeting in Tokyo, and a first draft of the final report will be completed prior to the 2017 CSLF Mid-Year Meeting. A finalized version of the report is expected in time for the 2017 CSLF Ministerial Meeting.

13. Report from Improved Pore Space Utilisation Task Force

Task Force Co-Chairs Brian Allison and Max Watson along with Task Force member Ryozo Tanaka gave a brief update on the task force, which was established at the November 2015 meeting in Riyadh. The purpose of the task force is to investigate the existing capabilities in improved pore space utilisation for CO_2 storage. This includes summarizing the effectiveness and readiness of various techniques and developing ideas for necessary R&D to develop capability in the most opportune technologies. Current task force members include Australia and the United Kingdom (as co-chairs), France, Japan, the United Arab Emirates, and the IEAGHG.

Mr. Allison and Dr. Watson briefly described the expected task force report contents. Included will be sections on well design (including flow control), injection operations (including pressure management and plume steering), and reservoir simulation (including geochemically enhanced injectivity). Mr. Tanaka gave a brief presentation about another section of the report, modified injection, which would include micro-bubble injection. Micro-bubbles of CO_2 are much smaller than ordinary macro-bubbles, and dissolve much more readily into saline brine as would be found in a geologic storage site.

The task force timeline will result in a final report by the 2017 CSLF Ministerial Meeting. Prior to that, the task force will be very active with its technical reviews and expects to have a draft of its final report in time for the 2017 CSLF Mid-Year Meeting. Following the presentation, a representative of Statoil, in Norway, expressed interest and was added to the task force.

14. Review of Technical Group Action Plan and Possible New Technical Group Activities

Technical Group Chair Åse Slagtern provided a brief update on the Technical Group Action Plan. Over the past three years, six Technical Group task forces have completed final reports. Last year, at the Riyadh meeting, three new task forces were formed. A special working group had identified many other possible areas of Technical Group activity, but decisions concerning these had been postponed. There had been some interest in two of these areas, Industrial CCS and Geo-steering / Pressure Management Techniques, but not quite enough to form task forces.

Ms. Slagtern stated that a preliminary discussion about future Technical Group activities had been done at the previous day's PIRT meeting. There had been agreement that the existing Advanced Pore Space Utilisation Task Force would take on the geo-steering activity, but not the pressure management part which would need to be part of a future activity on Storage Mitigation. There was consensus for the task force to take on geo-steering as a new focal area. Also, France had expressed an interest in the Industrial CCS activity. After a short discussion, Didier Bonijoly was requested to determine if France would be able to lead a new task force in that area. In the end, no new task forces were formed but there was agreement that the Technical Group would re-evaluate task force options at its next meeting.

15. Update on the ISO TC265 Committee

Tim Dixon gave a presentation about the International Organization for Standardization's Technical Committee on CO_2 Capture, Transportation and Geological Storage (ISO TC265). This committee was convened in 2011 with the mission of preparing standards for the design, construction, operation, environmental planning, risk management, monitoring and verification, and other activities related to CCS. Mr. Dixon stated that there are currently six working groups, each with its own set of activities. The standards development procedure works through consensus and is a multi-stage process. New work item proposals are first made into a working draft, and those that gain consensus from the working group are made into a committee draft. At that point a greater degree of working group consensus is required to move the proposal into the "draft international standard" phase, which then requires a comments period and consensus of the working group's panel of experts to become an ISO standard.

Mr. Dixon stated that the ISO TC265 currently includes twenty participating countries, eight observer countries, and also seven liaison organizations (including the CSLF). The committee as a whole has met seven previous times since its formation with the seventh meeting taking place in May 2016 in the United States. The next meeting will be in late November 2016 in Japan.

16. Report on the IEAGHG-CSLF Life Cycle Assessment (LCA) Workshop

Jasmin Kemper gave a short presentation about the IEAGHG-CSLF LCA Workshop, which was held in London in November 2015. The IEAGHG had, in 2010, published a report on "Environmental Evaluation of CCS Using Life Cycle Assessment", which described challenges surrounding use of LCA methodology in the context of carbon capture, utilization and storage (CCUS). Subsequent to the report there had been a request from the CSLF to do further work on this topic so the workshop was organized instead of a follow-up study. There were 23 participants with varying levels of LCA experience that represented different backgrounds (academia, industry, and NGOs). The workshop scope was focused on exploring the possible need for setting up guidelines for benchmarking and transparency of LCAs for CCUS.

Ms. Kemper stated that the workshop consisted of five sessions: Scene-setting, Goal and scope, Inventory analysis, Impact assessment, and Life cycle costing. There were several significant conclusions:

- Transparency about LCA methodology is essential and must be improved.
- There is a need to communicate how and why differences in LCAs come about.
- It is important to clearly distinguish LCA from carbon / greenhouse gas accounting and footprinting.
- Social LCA (which is somewhat subjective and involves issues such as health and safety) is an emerging area but is less mature and quantifiable than environmental LCA.

Ms. Kemper stated that based on the outcomes from this workshop, there appeared to be no need to update the 2010 IEAGHG report, though another LCA workshop might be a good idea in a few years. Other recommendations from the workshop were that awareness on this topic could be heightened by keynote or plenary presentations at conferences, and that it might be useful to develop a guidance / good practice document about LCA in collaboration with outside experts in this area.

17. Report on the International Workshop on Offshore CO_2 Storage

Tim Dixon gave a short presentation about the Offshore CO_2 Storage Workshop, which was held in April in the United States and was organized by the Bureau of Economic Geology (BEG) at the University of Texas. Other collaborators were the Centre for CCS at the South African National Energy Development Institute (SANEDI) and the IEAGHG, with support from the United Nations Framework Convention on Climate Change (UNFCCC) Climate Technology Centre & Network (CTCN) and the CSLF. The workshop was attended by representatives from thirteen countries, including seven developing countries.

Mr. Dixon stated that the goal of the workshop was to facilitate the sharing of knowledge and experiences among those who are currently involved in offshore CO_2 storage and those who are or may be interested. The first day of the workshop consisted of targeted plenary talks by experts ("What we know that you need to know"), while the second day featured country status and needs assessment reports, and also a guided discussion which came up with conclusions and recommendations:

- A follow-on workshop with deeper and more specific technical content is desirable.
- Other workshops – on infrastructure, storage resource assessment, and aimed more directly at developing countries – are also needed.
- There is a great need for international collaboration and a funding mechanism for a high-visibility pilot or demonstration project.
- An online resource page is needed with links to key information sources.
- Creation of an ongoing Offshore Network, perhaps by the IEAGHG, would be useful.

Mr. Dixon closed his presentation by mentioning that the CTCN had covered the cost for delegates from Nigeria and Ghana to attend the workshop, and this was the first ever funding by CTCN on a CCS activity. An IEAGHG report on the workshop was published in May 2016, and presentations from the workshop are available at the BEG website. The Secretariat was requested to make the Workshop summary and presentations also available at the CSLF website.

18. Otway Stage 2C Project Update

Max Watson provided an update on the CSLF-recognized CO2CRC Stage 2 Otway Project, located in Victoria, Australia. CO2CRC is the first company in Australia to have undertaken CO_2 geological storage, safely injecting, monitoring and containing more than 80,000 tonnes of CO_2 into varying rock formations.

Since its inception, the broader Stage 2 research program has intended to demonstrate that CO_2 storage can be safely conducted at scale within a geologic saline formation. Otway Stages 2A and 2B were a pre-operation appraisal that measured parameters affecting residual and dissolution CO_2 trapping in a saline formation. Stage 2C, launched in late 2015 and set to expand through to 2019, is the operational phase, and is monitoring 15,000 tonnes of injected CO_2 to obtain information on minimum detection limits, migration behavior, and determine the timing of plume stabilization.

Dr. Watson stated that the Stage 2C monitoring program is utilizing a 1x1 kilometer buried seismic receiver array for both active and passive 4D seismic monitoring of the injected CO_2. Preliminary results show that the CO_2 is safely migrating as predicted, seismic and pressure monitoring resolution is beyond expectation, and minimum detection levels of CO_2 have been identified. Next steps in the project are to continue monitoring the injected plume through to stabilization, including reservoir zone and above-zone pressure monitoring. CO2CRC, along with Lawrence Berkley National Laboratories and Curtin University will also assess the performance of fiber-optics as a less invasive alternative to geophones in seismic monitoring. With this small, short-term empirical trial at the Otway Project, a generic and validated workflow will be developed by CO2CRC for conforming long term plume predictions (including stabilization) through the use of early monitoring observations.

Dr. Watson concluded his presentation by providing a preview of the CO2CRC Otway Stage 3 program, which has the overall goal of delivering a permanently deployed subsurface and cost-effective real-time monitoring solution for industry. This will include increasing the efficiency of CO_2 monitoring with new and adapted technologies and finding ways to reduce the surface footprint and impact of monitoring activities. Dr. Watson stated that Stage 3 is open to international collaboration, and that expressions of interest in project participation have been strong and more are welcome.

19. Overview of the QICS Project: a Sub-Seabed Controlled Release Experiment

Steve Widdicombe, representing the United Kingdom's Plymouth Marine Laboratory, presented a summary of findings from the QICS Project, located on the west coast of Scotland, which monitored the release of 4.2 tonnes of CO_2 in an abandoned wellbore scenario. The CO_2 was injected over a 37 day period approx. 50 meters below the seabed into unconsolidated mud and silt beneath 11 meters of water. Dr. Widdicombe stated that results from the experiment indicated that a very complex CO_2 migration had occurred, with eventual creation of a chimney through the sediments. Gas plumes were readily revealed by acoustic monitoring, and quantified by use of hydrophones. The gas flow was heavily influenced by the tidal state, almost ceasing at high tide.

Dr. Widdicombe stated that an analysis of the results had indicated that approx. 15% of the injected CO_2 had been re-emitted as bubbles, approx. 35% had been re-emitted in a dissolved phase, and approx. 50% had been retained in the sediments. It was not yet known how much of the CO_2 retained in the sediments was physically trapped and how much was chemically bound. Biological response to the CO_2 release was limited to the release site, and both the number of species and the number of individuals recovered to pre-release levels within approx. three weeks. Dr. Widdicombe closed his presentation by mentioning that a larger controlled release experiment is part of the European Union's STEMM-CCS Project. For that experiment, there would be a deeper CO_2 release and results would be used to characterize a biogeochemical baseline at the Goldeneye sub-seabed storage formation in the North Sea off the northeast coast of Scotland.

20. Evaluation of Barriers to CO_2 Geological Storage Assessments

James Craig gave a short presentation about an initiative by the Clean Energy Ministerial CCUS Action Group to evaluate barriers to national storage assessments. A survey was done, covered 25 countries, that explored the extent of high-level assessments of geological CO_2 storage capacity, exposed potential barriers in determining these assessments, and learned how these barriers have been overcome for some countries. The survey questionnaire received 29 responses from 15 countries, with all respondents indicating that some level of storage assessment had been undertaken in their countries. The most common barriers reported involved data availability and quality, lack of policy and regulatory support for CCS, lack of industry support for CCS, and lack of funding for storage assessments.

Mr. Craig stated that a conclusion from this initiative was that unless CCS is on the political agenda, it is very unlikely that a national storage assessment or implementation of CCS will move forward. Developing countries, particularly where oil and gas resource development is still maturing, may have difficulties in finding the expertise for CO_2 storage assessments, but with international collaboration this can be overcome. Mr. Craig closed his presentation by stating the recommendation that a technical guide be produced for officials and organizations in developing countries on the implementation, structure, and approach for compiling a CO_2 storage resource. An IEAGHG report on this topic was published in February 2016.

21. Update from the Global Carbon Capture and Storage Institute (GCCSI)

Andrew Purvis provided a brief report about the GCCSI and its current priorities. Priority outcomes for 2016-2017 fall into two categories: fact-based influential advice / advocacy and authoritative knowledge sharing. For the former, it is important that CCS be increasingly portrayed as an emissions reduction technology that must be deployed to achieve a low-carbon future. Further, CCS must be positioned as a necessary technology for closing the gap between global climate ambitions (i.e., the 1.5 degrees C scenario) and current mitigation plans. To that end, key national and regional governments will need to confirm the important role of CCS in their carbon mitigation planning by implementing policy drivers that will encourage use of CCS. Concerning knowledge sharing, developing and sharing information that encourages the deployment of CCS will need to be an ongoing and necessary collaborative effort.

Mr. Purvis concluded his report by mentioning that the GCCSI recently published two special reports on the global status of CCS: "Introduction to Industrial CCS" and "Understanding Industrial CCS Hubs and Clusters".

22. Methodology for the United Nations Framework Classification (UNFC) for CCS

Wolfgang Heidug provided a brief report about the UNFC and its activities concerning CO_2 storage. The UNFC is a universally accepted and internationally applicable scheme for classification and reporting of fossil energy and mineral reserves and resources. Pore space is also a mineral resource, so the UNFC, through a task force, is working to develop a set of specifications for applying UNFC methodology to CO_2 storage. Dr. Heidug stated that he is a member of this UNFC task force (being chaired by Statoil in Norway), which has recently published a report on this topic that has been submitted to the United Nations Economic Commission for Europe (UNECE) for approval (the UNECE holds the pen on this activity). If accepted, this document could form the basis for comparison of CO_2 storage reserves worldwide.

23. Update on Future CSLF Meetings

Richard Lynch provided a short summary of upcoming CSLF events, including a preview of the next day's joint CCSA-CSLF Workshop on "CCS Post-Paris: Realising Global Ambitions". As for upcoming CSLF meetings, the 2016 CSLF Annual Meeting is being hosted by Japan during the week of October 3-7, and will include a day trip to the Tomakomai CCS Project. The Tokyo meeting page on the CSLF website is expected to be online by early August with meeting registration scheduled to open about mid-August. Mr. Lynch stated that no information is available yet for 2017 CSLF meetings.

24. Open Discussion and New Business

No additional new activities were proposed.

25. Review of Consensuses Reached and Action Items

Consensus was reached on the following items:

- The Technical Group will consider the presentation at the June 2015 meeting by the Chairman of the Task Force on CO_2 Storage Efficiency in Deep Saline Aquifers as the task force's final report.
- The Advanced Pore Space Utilisation Task Force will incorporate geo-steering into its activities as a new focal area.
- The Technical Group will re-evaluate possibilities for new task forces at the next meeting.

Action items from the meeting are as follows:

Item	Lead	Action
1	France	Determine if it can lead a new task force on Industrial CCS.
2	Secretariat	Make the summary and presentations from the CSLF Offshore Workshop (of April 2016) available at the CSLF website.

26. Closing Remarks / Adjourn

Åse Slagtern thanked the meeting host and sponsors, the Secretariat for its support, and the delegates for their active participation. She then adjourned the meeting.

Carbon Sequestration Leadership Forum
www.cslforum.org

CSLF-T-2016-07
28 July 2016

TECHNICAL GROUP

Action Plan Status

Background

At the Regina meeting in June 2015, a working group was formed to develop and prioritize potential new Action Plan activities. The working group presented its recommendations at the Riyadh meeting in November 2015, which resulted in three new task forces being formed in the areas of Offshore CO_2-EOR, Improved Pore Space Utilization, and Bio-energy with CCS. At the London meeting in June 2016, decisions on forming task forces in other areas were deferred.

This paper, prepared by the CSLF Secretariat, is a brief summary of the Technical Group's current actions, potential actions that have so far been deferred, and completed actions over the past three years.

Action Requested

The Technical Group is requested to review the Secretariat's summary Technical Group actions.

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CSLF-T-2016-07
28 July 2016

CSLF Technical Group Action Plan Status

(as of July 2016)

Current Actions

- Offshore CO_2-EOR (*Task Force chair: Norway*)
- Improved Pore Space Utilisation (*Task Force co-chairs: Australia and United Kingdom*)
- Bio-energy with CCS (*Task Force chair: United States*)

Potential Actions (*all of which have been deferred*)

- Geo-steering and Pressure Management Techniques and Applications (*Note: Geo-Steering will be incorporated into Improved Pore Space Utilisation action.*)
- Industrial CCS (*Note: France will determine if it can lead a task force for this action.*)
- Advanced Manufacturing Techniques for CCS Technologies
- Dilute Stream / Direct Air Capture of CO_2
- Global Residual Oil Zone (ROZ) Analysis and Potential for Combined CO_2 Storage and EOR
- Study / Report on Environmental Analysis Projects throughout the World
- Update on Non-EOR CO_2 Utilization Options
- Ship Transport of CO_2
- Investigation into Inconsistencies in Definitions and Technology Classifications
- Global Scaling of CCS
- Compact CCS

Completed Actions (*previous three years*)

- Technical Challenges for Conversion of CO_2-EOR Projects to CO_2 Storage Projects (*Final Report in September 2013*)
- CCS Technology Opportunities and Gaps (*Final Report in October 2013*)
- CO_2 Utilization Options (*Final Report in October 2013*)
- Reviewing Best Practices and Standards for Geologic Storage and Monitoring of CO_2 (*Final Report in November 2014*)
- Review of CO_2 Storage Efficiency in Deep Saline Aquifers (*Final Report in June 2015*)
- Technical Barriers and R&D Opportunities for Offshore Sub-Seabed CO_2 Storage (*Final Report in September 2015*)
- Supporting Development of 2nd and 3rd Generation Carbon Capture Technologies (*Final Report in December 2015*)

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DRAFT

MEETING SUMMARY
Projects Interaction and Review Team (PIRT) Meeting
London, United Kingdom
27 June 2016

Prepared by the CSLF Secretariat

LIST OF ATTENDEES

PIRT Active Members

Australia:	Andrew Barrett (Chair), Max Watson
Canada:	Eddy Chui
France:	Didier Bonijoly, David Savary
Japan:	Ryozo Tanaka
Netherlands:	Paul Ramsak
Norway:	Lars Ingolf Eide, Åse Slagtern (Technical Group Chair)
Saudi Arabia:	Hamoud Al-Otaibi
South Africa:	Tony Surridge
United Kingdom:	Brian Allison
United States:	Mark Ackiewicz
IEAGHG:	Tim Dixon

Other CSLF Delegates

Australia:	Paul Trotman
Italy:	Paolo Deiana
Japan:	Takashi Kawabata, Takura Okajima
Korea:	Chong Kul Ryu, Chang Keun Yi
Saudi Arabia:	Ahmed AlEidan
United States:	Jarad Daniels (Policy Group Chair)

CSLF Secretariat Richard Lynch

Observers

Canada:	Simon O'Brien
Japan:	Kimiko Nakanishi
Norway:	Britta Paasch
United Kingdom:	Mark Crombie
United States:	Sallie Greenberg, Judd Swift

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1. **Welcome**

Following a brief host country greeting by Brian Allison, PIRT Chairman Andrew Barrett welcomed participants to the 25th meeting of the PIRT. Mr. Barrett stated that the emphasis of the current meeting would be on how the PIRT could better interact with CSLF-recognized projects. Mr. Barrett noted that representatives of CSLF-recognized projects were present and that he looked forward to their suggestions on that topic.

2. **Introduction of Meeting Attendees**

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

3. **Adoption of Agenda**

The draft agenda for the meeting, which had been prepared by the CSLF Secretariat, was adopted without change.

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

The Meeting Summary from the November 2015 PIRT meeting in Riyadh was approved as final with no changes.

5. **Report from CSLF Secretariat**

Richard Lynch provided a two-part report from the Secretariat, which covered the status of CSLF-recognized projects and, PIRT consensuses from the November 2015 meeting in Riyadh.

Concerning the portfolio of CSLF-recognized projects, Mr. Lynch stated that as of June 2016 there were 34 active projects and 15 completed projects spread out over five continents. Recent changes include addition of the five projects which were recognized by the CSLF at its November meeting in Riyadh. For the current meeting, no new projects had been proposed for CSLF recognition.

Mr. Lynch reported that there were two consensuses from the Riyadh meeting. The PIRT recommended approval by the Technical Group of five projects:

- CO_2 Capture Project, Phase 3
- CO2CRC Otway Project, Stage 2
- Oxy-Combustion of Heavy Liquid Fuels Project
- Carbon Capture and Utilization Project / CO_2 Network Project
- Dry Solid Sorbent CO_2 Capture Project

Also, the PIRT recommended that the Technical Group assign a working group to formulate process and structure for future revisions of the CSLF Technology Roadmap (TRM). During the following day's Technical Group meeting, these recommendations were all accepted and approved.

6. **Current PIRT Activities**

Discussions of current PIRT activities centered on the ongoing update activities for the TRM. Mr. Barrett stated that the TRM working group had been formed at the Technical Group meeting in Riyadh and consisted of Australia (Chair), Norway, South Africa, the United Kingdom, the United States, the IEAGHG, and the CSLF Secretariat. At that meeting there had been consensus that the process for the TRM rewrite would use the

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2013 TRM as a foundation and refresh its content as needed, in order to keep the overall level of effort to a manageable level. Mr. Barrett stated that in the months following the Riyadh meeting there had been several meetings of the working group by teleconference and that the current focus was on updating Section 4 ("Identified Technology Needs"). The overall goal is to have a 2017 TRM in time for the expected end-of-2017 CSLF Ministerial Meeting.

Ensuing discussion provided valuable input on not only the content but also the desired timing of the rewrite process. There was consensus that the 2017 TRM should incorporate outcomes from the COP21 meeting in Paris, and also other relevant types of technologies such as Industrial CCS and Bioenergy with CCS (BECCS), both of which were only briefly mentioned in the 2013 TRM. It was also stated that the revised TRM should be clear on who will be its audience. Two existing areas, on Transportation and Infrastructure, will be combined into a single area with Norway as lead, and there was consensus that the TRM working group should change the structure of the TRM where needed. There was also agreement that the working group should create a survey for obtaining pertinent information from existing projects, which would assist the TRM rewrite effort. The survey would focus on technical needs.

The CSLF Policy Group Chair, Jarad Daniels, suggested that the TRM working group compress its work plan timeline so that a final draft of the 2017 TRM would be published in time for the 2017 CSLF Mid-Year Meeting. This timing change would allow recommendations from the TRM to be integrated into the planning for the 2017 Ministerial Meeting. There was agreement to make this timeline change.

7. Future PIRT Activities

Mr. Barrett stated that one of the functions of the PIRT, as stated in its Terms of Reference, is to: "Ensure a framework for periodically reporting to the Technical Group on the progress within CSLF projects". To that end, there was general agreement that the PIRT was not doing enough to engage projects that have been recognized by the CSLF. Some of these projects have been involved in CSLF workshops but for many of the recognized projects, the PIRT has not had very much interaction. Several suggestions were offered to improve the situation: Technical Group Chair Åse Slagtern stated that more "Lessons Learned" workshops would be of high interest to the CSLF, Ahmed AlEidan suggested that the emphasis should be on finding ways to engage projects outside of meetings and workshops, and Sallie Greenberg mentioned that some of the CSLF-recognized projects may now be at the stage where intellectual property concerns have diminished and might be more disposed to share knowledge.

In the end, agreement was reached on a way forward that would improve interaction between the PIRT and recognized projects. The CSLF Secretariat and Dr. Greenberg (representing the CSLF-recognized Illinois Basin – Decatur Project) were requested to jointly develop a useful format (neither superficial nor onerous) for projects to report their status. Once this is available, PIRT delegates from Australia (Max Watson), Canada (Eddy Chui), and the United States (Mark Ackiewicz) would use this to engage project sponsors in their countries (targeting projects which have not participated in CSLF workshops) so that a sample status report on 4-8 projects can be finished in time for the 2016 CSLF Annual Meeting in October.

One other area of ongoing PIRT activity is technology workshops. Ryozo Tanaka stated that there would be a technical workshop at the upcoming 2016 CSLF Annual Meeting in

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Tokyo. Due to the short time between the Mid-Year Meeting and the Annual Meeting, Mr. Tanaka and Mr. Lynch were requested to develop a structure for the workshop as expeditiously as possible.

8. Open Discussion on Possible New Technical Group Activities

The CSLF Technical Group Chair, Åse Slagtern, made a short presentation that summarized existing Technical Group activities and possible new ones in advance of a more detailed discussion during the next day's full Technical Group Meeting. There are currently three active task forces besides the PIRT: Improved Pore Space Utilization (co-chaired by Australia and the United Kingdom), Bioenergy with CCS (chaired by the United States), and Offshore CO_2-EOR (chaired by Norway). Decisions on forming task forces in two other areas, Industrial CCS and Geo-Steering and Pressure Management Techniques, had been postponed during the previous Technical Group Meeting.

Max Watson stated that the geo-steering activity could be taken up by the Improved Pore Space Utilization Task Force, but not elements associated with risk management. For that, a separate activity on Storage Mitigation would be needed. Didier Bonijoly offered that the Industrial CCS activity would need an active 'community' for a task force and that France's "Club CO_2" might be able to assist, but he was not yet ready to propose creation of a task force until he checked with that association. Ms. Slagtern took all of this into consideration and stated that she would not propose that the Technical Group create any new task forces at the current Mid-Year meeting.

9. Open Discussion and New Business

There was no new business offered or further discussion on any topic.

10. Adjourn

Mr. Barrett thanked the attendees for their interactive participation and adjourned the meeting.

Summary of Meeting Outcomes

- The 2017 TRM should incorporate outcomes from the COP21 meeting in Paris, and also other relevant types of technologies such as BECCS that were not mentioned in the 2013 TRM.
- The TRM working group should change the structure of the TRM where needed.
- The TRM working group should create a "technical needs" survey for obtaining pertinent information from existing projects, in order to assist the TRM rewrite effort.
- The TRM working group should compress its work plan timeline so that a final draft of the 2017 TRM would be published in time for the 2017 CSLF Mid-Year Meeting.
- CSLF Secretariat and Dr. Sallie Greenberg (representing the CSLF-recognized Illinois Basin – Decatur Project) should jointly develop a useful format (neither superficial nor onerous) for CSLF-recognized projects to report their status.
- PIRT delegates from Australia, Canada, and the United States should use the new project reporting format to engage projects located in their countries (approx. 4-8 projects in total) and prepare short status summaries in time for the 2016 CSLF Annual Meeting.

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- PIRT delegate from Japan (Ryozo Tanaka) and CSLF Secretariat should develop a structure for a technical workshop to be organized as part of the upcoming 2016 CSLF Annual Meeting.

Carbon Sequestration Leadership Forum
16 September 2016
www.cslforum.org

PROJECTS INTERACTION AND REVIEW TEAM

Engagement of CSLF-recognized Projects

Background

At the London meeting in June 2016, there was consensus by the CSLF Projects Interaction and Review Team (PIRT) to find ways to improve its interactions with CSLF-recognized projects. To that end, the CSLF Secretariat, along with Dr. Sallie Greenberg (representing the CSLF-recognized Illinois Basin – Decatur Project), developed a new format for projects to report their status. As an initial trial, PIRT delegates from Australia, Canada, and the United States used this new reporting format to engage several projects located in each of their countries.

This summary, prepared by the CSLF Secretariat, is a collection of reports received from ten CSLF-recognized projects:

Australia
- CarbonNet Project
- Gorgon CO_2 Injection Project
- The South West Hub Project

Canada
- The Alberta Carbon Trunk Line
- The Boundary Dam Integrated CCS Project
- CANMET Energy Technology Centre (CETC) R&D Oxyfuel Combustion for CO_2 Capture
- Quest Project

United States
- Illinois Basin – Decatur Project
- Illinois Industrial CCS Project
- Michigan Basin Development Phase Project

Action Requested

The PIRT is requested to review the information received from the projects.

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Project Name: CarbonNet

Brief non-technical description:
The CarbonNet Project is investigating the potential for establishing a commercial scale CCS hub network, bringing together multiple CO_2 capture projects in the Latrobe Valley, Victoria Australia, transporting CO_2 via a common-use pipeline and injecting it deep into offshore underground storage sites in the Gippsland region. The project is jointly funded by the Commonwealth and Victorian governments.

Is the project still active? *Yes*

> If still active, what have been the important factors in its continued progress, and why?
> *The project is fortunate in that the Gippsland region in Victoria offers considerable potential for CCS. The nearby Latrobe Valley contains the second largest deposit of brown coal (lignite) in the world and is home to significant existing and potential future industry. The offshore Gippsland Basin is located close to these brown coal reserves and is well suited for geological carbon storage. The National Carbon Taskforce report (September 2009) considered the Gippsland Basin as having the highest technical ranking of 25 major basins across Australia and the largest storage potential of any east coast basin.*
>
> *As a hub based concept to support multiple potential sources of CO_2, CarbonNet has sought to meet the needs of potential coal-to-products processes (urea, hydrogen etc), as well as the power sector. This has enabled the project to progress despite challenging market conditions in the power sector (falling demand, mandated renewables targets). Support from the Federal and State governments has been critical in maintaining continued progress of the project. CarbonNet have worked closely with the government to progress CCS within existing policy settings, identifying deficiencies and presenting solution for both its own and future CCS projects.*

Please briefly describe the overall project timeline (with emphasis on next six months):
CarbonNet, as a government funded and lead project, has focused on increasing the storage certainty to de risk subsequent investment decisions for the rest of the

CCS value chain. This has involved work that goes beyond the typical pre commercial / pre competitive data acquisition undertaken by government organisations such as Geoscience Australia. CarbonNet's storage characterisation and site selection process has intentionally adopted a portfolio approach to provide robustness and optionality should geological data for one site be found lacking, or other needs/constraints require an alternate site to be prioritised.

The project is finalising a plan to progress to the next stage of development, involving appraisal of its prioritised storage site. The project aims to obtain a Declaration of Storage and then progress towards obtaining a CO_2 Injection License by 2020 at which time the project will be transitioned into the commercial sector.

What kinds of sharable information have been produced?
CarbonNet has an agreement with the Global CCS Institute to produce knowledge share reports available on the Website. There are multiple reports available including:

3 whole of project reports:

- *A Historical Perspective – Which explores the history of CCS in Victoria from 2003 and the initial phase of CarbonNet from 2009 to 2014.*
- *Developing a business model for a CCS hub network*
- *GCCSI Regulatory Test toolkit for Victoria*

5 reports on storage:

- *Site Characterisation for Carbon Storage in the near shore Gippsland Basin*
- *CarbonNet storage site selection and certification: challenges and successes Gippsland Basin*
- *Integrity of wells in the near shore Gippsland Basin Victoria*
- *3D mapping and correlation of intraformational seals within the Latrobe Group in the nearshore Gippsland Basin*
- *GipNet – baseline environmental monitoring and technology validation for near shore carbon storage*

2 reports on transport:

- *Dispersion modelling techniques for CO_2 pipelines in Australia – Report produced for BCIA, with support from CarbonNet, ANLEC R&D, GCCSI*
- *Development of a CO_2 specification for a CCS hub network*

Please describe any interesting outcomes or gains in knowledge.
There are significant opportunities for CarbonNet to establish a foundation CCS network around coal-to-products proponents in the urea and hydrogen sectors

where total life cycle costs for CCS have been assessed at less than $50 per tonne of CO_2*. A large scale and a high utilisation rate of the network is important to realise low costs in the transport and storage components of the network to minimise total costs for individual* CO_2 *sources. This will provide opportunities for CCS in the power sector in the medium to longer term.*

While Australia and Victoria have in place legislative and regulatory frameworks for CO_2 *storage, the pathway has been untested and therefore regulators have been particularly cautious in the application. An outcome of this project is a deep understanding of Australia's regulatory approval schedule and opportunities to expedited the process to meet the needs of private sector proponents. . Of particular interest in the future will be whether the established long term liability regimes under Australian and Victorian legislation represent an impediment to private sector investment in the development of storage sites.*

Who is the project's main point-of-contact for the CSLF?
Ian Filby – Project Director
Ian.filby@ecodev.vic.gov.au

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Project Name: Gorgon Carbon Dioxide Injection Project

Brief non-technical description:
The Gorgon Carbon Dioxide Injection Project will safely dispose of over 100 million tonnes by underground injection into the Dupuy Formation two kilometres below Barrow Island, off the northwest coast of Australia.

The project is an integral component of the larger Gorgon Project which involves the initial development of the Gorgon and Jansz gas fields, the processing of that gas into liquefied natural gas for export and domestic gas for consumption in Western Australia. The reservoir carbon dioxide that is routinely extracted during the gas processing operations is to be injected at a rate of between 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.

Is the project still active? *Yes.*

Construction of the Gorgon Project commenced in 2009. Commissioning operations, which will occur over a period of several years, commenced in 2015 and the first liquefied natural gas cargo was exported in 2016. The Carbon Dioxide Injection component of the project will be commissioned in 2017 once there are significant volumes of reservoir carbon dioxide being produced from the gas processing facility.

The Gorgon Carbon Dioxide Injection Project is the largest greenhouse mitigation project to be undertaken by industry globally.

Apart from some minor government funding ($60 million contribution to the capital cost of the Injection Project under the Australian Government's Low Emissions) it is not dependent on any other form of government policy support.

Please briefly describe the overall project timeline (with emphasis on next six months):
The continuation of construction and commissioning of the overall Gorgon Project. The Gorgon Project is a huge and highly compact undertaking and will take several years to

bring to full production. The Injection Project is scheduled to commence injection towards the end of that process.

What kinds of sharable information have been produced?

Chevron as operator of the Gorgon Project has provided updates to groups such as the CSLF and the IEA once significant milestones have been passed.

Please describe any interesting outcomes or gains in knowledge.

There is no technical, legal or regulatory barrier preventing such projects from moving forward. They are however costly and until the question of how to fund future projects is addressed, large scale deployment of similar greenhouse mitigation projects will remain problematical.

Who is the project's main point-of-contact for the CSLF?

John Torkington

Manager - Climate Change Team

Chevron Australia Pty Ltd

250 St Georges Terrace
Perth, WA 6000
Tel +61 8 9216 4025
Mobile 0408 947 130
John.Torkington@chevron.com

Project Name: The South West Hub Project

Brief non-technical description:
The South West Hub (SW Hub) project is a pre-feasibility investigation into the potential for commercial scale CO_2 storage in the South West of Western Australia (WA). The project is currently managed by the WA Government through the Department of Mines and Petroleum (DMP). The project is non-conventional in that it relies on the concept of "migration assisted trapping" (MAT) or residual trapping for CO_2 containment in the proposed storage aquifer.

Is the project still active? *Yes*

If still active, what have been the important factors in its continued progress, and why?
The most important factors have been:

- *Funding support from the Commonwealth and State Governments. The funding support has provided a level of certainty and demonstrated a commitment by both governments to investigate potential CO_2 storage options for future industry development;*
- *Collaborations with industry and research partners. The collaborations have led to increased technical understanding of the potential reservoir and commercial drivers for development. The collaborations have increased industry and research capabilities in CCS; and*
- *A general level of community acceptance of the project. This acceptance will be a key factor in determining whether a commercial project is a viable option.*

Please briefly describe the overall project timeline (with emphasis on next six months):
Preliminary (desktop) investigations commenced in 2007. This was followed by a data acquisition process that has included 2D and 3D seismic surveys and the drilling of 4 stratigraphic wells. Information from the data acquisition process has been incorporated into static and dynamic modelling to establish confidence levels for injection rates, well count and CO_2 containment. The modelling outcomes will be released in September 2016.

The program of activity for the next six - twelve months will be to conduct additional laboratory and desktop analysis. The results of this process will be utilised to create additional modelling scenarios to further reduce identified uncertainties. The results of this process will inform an investment decision for potential future field data collection (drilling) activity.

What kinds of sharable information have been produced?
Numerous technical reports along with raw data and summaries of community engagement activity are made freely available on the DMP website at: www.dmp.wa.gov.au/ccs (general reports) and www.dmp.wa.gov.au/wapims (raw data)

Please describe any interesting outcomes or gains in knowledge.
As highlighted above, the SW Hub project relies on the concept of MAT or residual trapping rather than a conventional impenetrable formation layer acting as a seal. The recent modelling conducted for the SW Hub project indicates that commercial quantities of CO_2 could be contained through residual trapping in the identified area.

Who is the project's main point-of-contact for the CSLF?
Dominique Van Gent, Project Coordinator, Department of Mines and Petroleum
Dominique.vangent@dmp.wa.gov.au
+61 8 9791 2040

Martin Burke, Project Manager, Department of Mines and Petroleum
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+61 8 9222 3464

Project Name: The Alberta Carbon Trunk Line

Brief non-technical description:
The Alberta Carbon Trunk Line (ACTL) is a fully integrated carbon capture and storage system that will have the potential to compress, transport and store 14.6 million tonnes of CO_2 per year at full capacity. Pioneered in Alberta, Canada by Enhance Energy Inc., the ACTL is the first large-scale Enhanced Oil Recovery (EOR) and storage project in Alberta, utilizing Alberta's wealth of innovative, exportable, and local expertise to create thousands of new jobs while decreasing Canada's carbon footprint.

The ACTL will initially capture and compress CO_2 from two industrial sources: The Agrium Redwater Fertilizer Plant and the North West Redwater Partnership's Sturgeon Refinery. The Sturgeon Refinery is the first greenfield refinery to be built in Canada since 1984. It is also the world's first bitumen refinery which will combine the already proven processes of gasification technology with an integrated carbon capture and storage solution. The process is optimized to minimize the environmental footprint of the facility and make bitumen refining sustainable in Alberta. The refinery is set to be operational at the end of 2017.

The ACTL consists of a 240-kilometre pipeline that will create the CO_2 gathering and distribution infrastructure required for the cost-effective management of CO_2 emissions from facilities in Alberta's Industrial Heartland and throughout central Alberta. To add to this environmental advantage, the stored CO_2 will be injected into depleted oil reservoirs for enhanced oil recovery. These oilfields will see significant increases in production as CO_2 is permanently stored in the reservoir, which will provide the economic stimulus of additional jobs in construction, manufacturing, research and a host of other industries. Alberta will also benefit from the incremental royalties and taxes it will generate through EOR.

Is the project still active? *Yes.*

> If still active, what have been the important factors in its continued progress, and why?
> *The Project is still active, but not yet operational. Both the ACTL and the Sturgeon Refinery are under construction and set to be operational at the end of 2017. Timing delays for the ACTL were mostly due to the construction timing of the $8.5B Sturgeon Refinery. The ACTL timeline needed to align*

with the timing of the CO_2 availability. Continued support from both the provincial and federal governments have been important factors in allowing the Project's continued progress.

Please briefly describe the overall project timeline (with emphasis on next six months):
THE ACTL is in its final phase of project financing and is targeting full construction to occur over the coming 12-18 months for project completion near the end of 2017. The main CO_2 supply for the ACTL will come from the North West Redwater Partnership's Sturgeon Refinery. The Refinery is currently at peak construction and will begin commissioning in 2017.

What kinds of sharable information have been produced?
[*http://www.enhanceenergy.com/video/Enhance_EOR.mp4*](http://www.enhanceenergy.com/video/Enhance_EOR.mp4)

Please describe any interesting outcomes or gains in knowledge.
The project team hopes to have outcomes and gains in knowledge to share after the project is complete and in operations mode.

Who is the project's main point-of-contact for the CSLF?
Alyssa Haunholter
Vice President Government Relations
Enhance Energy
ahaunholter@enhanceenergy.com
+1 780-504-2623

Project Name: The Boundary Dam Integrated Carbon Capture and Storage Project

Brief non-technical description:

The Boundary Dam Integrated Carbon Capture and Storage Project is SaskPower's flagship CCS initiative. Through the development of the world's first and largest commercial-scale CCS project of its kind, SaskPower is making a viable technical, environmental and economic case for the continued use of coal.

The Boundary Dam CCS Project rebuilt a coal-fired generation unit with carbon capture technology, resulting in low-emission power generation. In the fall of 2014, the project came online.

This project transformed the aging Unit #3 at Boundary Dam Power Station near Estevan, Saskatchewan into a reliable, long-term producer of more than 110 megawatts (MW) of base-load electricity, capable of reducing greenhouse gas emissions by up to one million tonnes of carbon dioxide (CO_2) each year, the equivalent of taking more than 250,000 cars off Saskatchewan roads annually.

The captured CO_2 is sold and transported by pipeline to nearby oil fields in southern Saskatchewan where it will be used for enhanced oil recovery. CO_2 not used for enhanced oil recovery will be stored, permanently and safely more than two miles underground in the Aquistore Project.

In addition to CO_2, SaskPower will sell other byproducts captured from the project. Sulphur dioxide (SO_2) is captured, converted to sulphuric acid and sold for industrial use. Fly ash, another byproduct of coal combustion, is also sold for use in ready-mix concrete, pre-cast structures and concrete products.

Is the project still active? *Yes*

If still active, what have been the important factors in its continued progress, and why?

The plant is nearing two full years of operation. For the period of October 2014 to the end of August 2016 the plant has captured just over one million tonnes. SaskPower's goal is to capture 800,000 tonnes of CO_2 in 2016, which meets the needs of its offtaker and exceeds federal emission regulations.

Please briefly describe the overall project timeline (with emphasis on next six months):

What kinds of sharable information have been produced?

SaskPower releases a monthly progress update on the operation of the carbon capture facility. Through a partnership with BHP Billiton, SaskPower has launched The International CCS Knowledge Centre. This entity is building relationships around the world by sharing lessons learned at the Boundary Dam CCS Project. Its mission is to help the development and adoption of CCS technologies worldwide.

Please describe any interesting outcomes or gains in knowledge.

Through SaskPower's unique experience in applying CCS technology to the production of coal-fired electricity on a commercial scale, it has identified significant lessons learned that will allow it to reduce costs by up to 30% on future CCS retrofits.

Who is the project's main point-of-contact for the CSLF?

Michael J. Monea
President & Chief Executive Officer
The International CCS Knowledge Centre
an initiative of BHP Billiton and SaskPower

Project Name: CANMET Energy Technology Centre (CETC) R&D Oxyfuel Combustion for CO_2 Capture

Brief non-technical description:
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.

Is the project still active? *No.*

If not, when did it end, and why?
It was ended in December 2009 upon completion of the Work Program of Phase 9 of this multi-phase project. Further pilot-scale research on the 1st generation oxy-fuel combustion systems was deemed unnecessary by the project's consortium members, due to the fact that the technology had reached the level of maturity ready for pre-commercial field demonstration by that time (as evidenced by a few oxy-fuel demonstration projects such as Vattenfall's Schwarze Pumpe 30 MW pilot plant in Germany that achieved nearly 100% CO_2 capture by November 2009).

If still active, what have been the important factors in its continued progress, and why?
While the project is not active, but the research work on the new generation of oxy-fuel combustion systems is ongoing at CanmetENERGY in Ottawa, with focus on high pressure oxy-fuel combustion processes and their integration with advanced power cycles (e.g., supercritical CO_2 cycles).

Please briefly describe the overall project timeline (with emphasis on next six months):
This was a multi-year, multi-phase project that was started in 1996 and completed in 2009.

What kinds of sharable information have been produced?

The project produced significant amount of information and data that were recorded in confidential reports over the years. However, some of the results related to processes for oxy-combustion and CO2 capture systems as well as data obtained from pilot-scale experiments, were presented in several international conferences and subsequently published in their proceedings.

Please describe any interesting outcomes or gains in knowledge.

Over the years, this project generated valuable knowledge and interesting results in the area of oxy-fuel combustion systems with CO2 capture. This includes unique data from pilot-scale combustion experiments, development of new burners, demonstration of hydro-oxy fuel combustion with coal, processes for pollutant control in oxy-fuel systems, proprietary CO2 capture processes and proof-of-concept pilot-scale test facilities, several patents and many confidential technical reports. The learning from this project persuaded a few members to further consider this technology for commercial scale deployment and conducting several feed studies for utility scale oxy-fuel power plants with CO2 capture.

Who is the project's main point-of-contact for the CSLF?

The Project Leader and point-of-contact was Dr. Kourosh Zanganeh (Kourosh.zanganeh@canada.ca) of Natural Resources Canada's CanmetENERGY in Ottawa.

Project Name: Quest

Brief non-technical description:
Quest is a large-scale, fully integrated CCS project, located at Fort Saskatchewan, Alberta, Canada, including capture, transportation, storage, and monitoring, which will capture and store up to 1.2 million ton CO_2 per year 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.

Is the project still active? *Yes*

If still active, what have been the important factors in its continued progress, and why?

- *Continued financial support from the provincial and federal governments*
- *Operational success – everything is working as well as or better than expected*

Please briefly describe the overall project timeline (with emphasis on next six months):
Quest is currently in commercial operations and has already captured and injected more than one million tonnes of CO_2 in the past year. Over the next six months we expect to continue capture and injection at current levels, and to continue collecting MMV data. We also plan to update our reservoir model and to revise our plume predictions to take into account our recent learnings.

What kinds of sharable information have been produced?
Information sharing was a condition of our agreement with the Alberta provincial government. As a result, much of the information gathered and created during the Quest project development is freely available on the government website, including virtually all engineering and subsurface details:
http://www.energy.alberta.ca/CCS/3848.asp

Please describe any interesting outcomes or gains in knowledge.
A key outcome has been the overall success of the full integrated project over the first year of operation, with all aspects of Quest meeting or exceeding the plan.

Both capture efficiency and reservoir performance have been better than expected, leading to fairly significant reductions in operating costs.

A variety of MMV technologies have been deployed, including a new laser-based atmospheric monitoring system at each of the three well sites. The lack of locatable microseismic events has confirmed the expectation that CO_2 injection in the BCS would not generate a significant microseismic response.

Who is the project's main point-of-contact for the CSLF?

Simon O'Brien

Simon.Obrien@shell.com

Project Name: Illinois Basin – Decatur Project

Brief non-technical description:
The Midwest Geological Sequestration Consortium (MGSC) large-scale CO_2 storage demonstration project, the Illinois Basin – Decatur Project (IBDP), has stored one million tonnes of CO_2 in a deep saline reservoir in the central portion of the United States. Carbon dioxide at IBDP was captured from ethanol production at Archer Daniels Midland and stored more than 2,000m beneath the surface. The IBDP began in 2007 and is being conducted over three phases – pre-injection, injection, and post-injection. The project is currently in a three to five-year post-injection phase monitoring the stored volume of CO_2 at the site.

Is the project still active? *Yes. Currently in post-injection phase.*

If not, when did it end, and why?
If still active, what have been the important factors in its continued progress, and why?
Important factors toward continued progress include a very supportive and collaborative industrial partner (ADM), detailed site characterization prior to and during injection, thoroughness on the part of the US DOE and project team to ensure goals and objectives are being met, stakeholder engagement incorporated into project management, and strong technical leadership.

Please briefly describe the overall project timeline (with emphasis on next six months):
The IBDP was funded in 2007 and is conducted over three periods – pre-injection (2007-2011), injection (2011-2014), and post-injection (2014-2017(9)). IBDP is currently in the post-injection monitoring phase and is conducting continuous pressure/temperature monitoring in the reservoir, annual fluid sampling in the storage zone and above the primary seal, and conducting annual logging to ensure well integrity and plume monitoring. The next six months will be heavily focused on the analysis of plume location, microseismic results from injection, and the reworking of the deep monitoring well to improve performance and long-term integrity.

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What kinds of sharable information have been produced?

IBDP has a wide-variety of communication materials available, a website www.sequestration.org, and is currently working with partners in Norway to establish data sets that can be shared among researchers globally.

Please describe any interesting outcomes or gains in knowledge.

There are many interesting outcomes and gains in knowledge from IBDP. The one most researchers find unique is our microsesimic data set which is one of the most comprehensive data sets of geomechancial and geophysical data related to the injection of CO_2 in a deep saline reservoir. We are presently actively working to understand the connection between the geomechanical reservoir response and plume migration.

Who is the project's main point-of-contact for the CSLF?

Sallie E. Greenberg, Ph.D.
Associate Director – Energy Research and Development
Illinois State Geological Survey
University of Illinois at Urbana-Champaign
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Champaign, IL 61821
sallieg@illinois.edu
+1 217 244 4068

Project Name: Illinois Industrial Carbon Capture and Storage Project

Brief non-technical description:
This project, located in Decatur, Illinois, will be demonstrating an integrated system for capturing approximately 1.0 million tons/yr of carbon dioxide from an industrial source (ethanol production) and geologically storing it in the Mount Simon Sandstone, a saline reservoir, which covers portions of the Midwest including central and southern Illinois. This will be the first project operating with the U.S. Environmental Protection Agency's Class VI injection well permit for geological storage of carbon dioxide.

Is the project still active? *Yes*

If still active, what have been the important factors in its continued progress, and why?

The main attributes that allowed the project to move forward were:

1) *Large source of CO_2 that was cost effective to capture (i.e. low capital and operational expense).*
2) *The site is located on a geologic formation that has the potential to safely store billions of tons of CO_2 (reduction in transportation cost – local storage).*
3) *Front end loading of public funds to reduce project risk (i.e. using public funding to offset most of the capital expense and allowing the operator to take on the operational cost.)*
4) *Availability of CO_2 storage tax credits (45Q) to reduce operational expense.*

Please briefly describe the overall project timeline (with emphasis on next six months):
2009 – Q3: Feasibility Study
2010 – Q3: Project Engineering
2011 – Q3: Began Construction and Environmental Permitting
2012 – Construction, Drilled and Cased 2 Monitoring Wells
2013 - Substantially Completed Construction except Injection Well.

2014 – Began limited commissioning activities, completed all facility construction (i.e. compression, dehydration, electrical substation, and transmission pipeline).
Q4 2014 USEPA issued final UIC Class VI permit allowing the construction of the injection well.
2015 – Injection Well Construction and Final Completion of Monitoring Wells.
2016 – Full Unit Commissioning and EPA review of well completion documentation
2017 – Q1: Start –up of injection operation

What kinds of sharable information have been produced?
The project has not started operation, therefore the sharable information is related to:

1) *Site Characterization, (i.e. methods applied and site geologic information)*
2) *Engineering and Construction (i.e. construction cost, equipment selection, engineering, system integration, site monitoring methods, and instrumentation.)*
3) *UIC Class VI Permitting Experience.*

Please describe any interesting outcomes or gains in knowledge.
Interesting experiences and achievements are related to the project development, design, construction, permitting, and operational commissioning.

Who is the project's main point-of-contact for the CSLF?
Scott McDONALD
Biofuels Development Director
Project Director, IL-ICCS Project
Archer Daniels Midland Company
1001 N. Brush College Rd.
Decatur, IL 62521 USA
+1 217 451-5142: Direct
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scott.mcdonald@adm.com

Project Name: Michigan Basin Development Phase Project

Brief non-technical description:

The Midwest Regional Carbon Sequestration Partnership (MRCSP), established and led by Battelle with funding from the United States Department of Energy (DOE) and others, is assessing the technical potential, economic viability, and public acceptability of CCS/CCUS within its region. MRCSP is now well into the 10-year Phase III, or Development Phase, of the research. This phase entails implementing a large volume CO_2 injection test in Michigan, continuing regional geologic characterization activities, participating in several smaller scale research activities, and communicating results with stakeholders.

The Michigan Basin Development Phase project is designed to inject and monitor approximately one million metric tons of CO_2 in depleted oil and gas fields undergoing enhanced oil recovery (EOR) operations. The source of the CO_2 for the test is man-made (natural gas processing) and the site has existing surface and well infrastructure. In cooperation with the site host, Core Energy LLC, CO_2 is being injected into about ten small oil fields in different stages of the oil production life cycle: late-stage, active CO_2-EOR, and new CO_2 flood. The individual fields are part of the Silurian-aged pinnacle reefs with containment provided by many layers and thousands of feet of low-permeability carbonate and evaporites. Substantial quantities of oil and gas have been produced from these ancient reefs since the 1960's. Today many of the reefs are at or near their economic limit for primary production of oil and gas. Combined, such reefs could store several hundred million metric tons of CO_2 and, when combined with EOR, could provide economic benefit through incremental oil production.

Data is being collected to help develop strategies for optimizing future CO_2 EOR and storage projects. The project team developed a conceptual geologic model of the injection site using historical data to provide insight into the impact of geologic heterogeneity and hydrocarbon production history on CO_2 storage potential. The geologic model was used as the basis for the numerical models that simulate reservoir behavior in response to CO_2 injection and provide estimates of key parameters such as injectivity and capacity. Monitoring data is being used to evaluate reservoir properties via pressure data analysis, to calibrate models, to evaluate the usefulness of monitoring technologies, and to account for net CO_2

stored in the reefs. The practical experience and knowledge gained from these tests will provide data for improving injectivity and capacity estimates, and demonstrate storage capacity within a regionally significant potential storage resource.

Is the project still active? ***Yes***

If still active, what have been the important factors in its continued progress, and why?

- *Availability of an appropriate host site and the host company's willingness and flexibility in working with the MRCSP team to address key technical challenges.*
- *Consistent source of federal funding and significant existing infrastructure available for the project has been an important factor in continued progress. In general, public-private partnerships provide a way to bridge barriers when economic and policy incentives are insufficient to drive technology development.*
- *Ability to build on success of the Phase II program. Three small-scale field tests, including one in the Michigan Basin, resulted in an experienced research and industry project team capable of developing and implementing the Phase III Project within budget and schedule.*
- *Other enabling factors included sufficient data to select, design, operate and monitor the site, a workable regulatory framework, existing infrastructure and CO_2 source, and public acceptance.*

Please briefly describe the overall project timeline (with emphasis on next six months):
Tasks to be completed in the next six months (and beyond) include:

- *<u>Regional geologic characterization</u>: An update to the initial regional source-sink analysis performed circa 2005 will be completed to reflect current status and trends for large-point CO_2 sources. The MRCSP Geoteam will continue to progress on preparing topical reports that describe regional characteristics relevant to CCS/CCUS. A prospective storage estimate of the Appalachian Basin region in eastern Ohio will be completed. Work will also continue on offshore CO_2 storage assessment in the Baltimore Canyon Trough area in the Atlantic offshore region.*
- *<u>Public Education and Outreach</u>: The website is being transferred to a mobile friendly platform. Project results will be presented at professional meetings, e.g., American Association of Professional Geologists (AAPG), Society of Professional Engineers (SPE) and Greenhouse Gas Control Technologies*

(GHGT) conference. MRCSP/Battelle will also host the 2017 meeting of IEAGHG Monitoring Network meeting in Traverse City, Michigan.

- *Late-Stage Reef Post Injection Monitoring: Post injection monitoring activities including vertical seismic profile survey, microseismic monitoring analysis, borehole gravity meter survey, and pulsed neutron capture (PNC) logging will be completed. A new characterization well will be drilled in the reef to evaluate post-injection changes and improve reservoir models. Resulting information will be used to update the static and dynamic models and evaluate containment.*
- *Active EOR reef Monitoring and Accounting: Continue monitoring in eight active EOR reefs and analyzing pressure data. The metering system at the central processing facility is being upgraded to reduce margin of error in the CO_2 accounting system. One new well be drilled, which will be used for additional characterization data and to evaluate oil production and CO_2 recycling in a new EOR flood.*
- *New CO_2 Flood Planning: Field work planning and preparation to drill two new characterization wells in a new EOR flood. One well will be used for injection and the other for monitoring, with advanced monitoring options being considered.*
- *Project Management: The next annual MRCSP meeting for industry and research partners, as well as for other project stakeholders and collaborators, will be held in November.*

What kinds of sharable information have been produced?
The project information is shared via the MRCSP Website (www.mrcsp.org); technical reports; papers; and presentations.

Please describe any interesting outcomes or gains in knowledge.
Key takeaways include:

- *The Michigan Basin test is nearly 60% completed (>575,000 net metric tons CO_2) and CO_2 accounting framework has been established for CO_2 retained in reservoirs during and after active EOR operations.*
- *In implementing CCS programs in depleted fields, ability to work with existing infrastructure and existing data, which may at times be incomplete, is crucial. The verification framework for CO_2 retained from past operations must be flexible to incorporate uncertainties in older operational data.*

- *In some cases, baseline monitoring will not be possible, if CO_2 flooding started prior to CCS evaluation. Accounting for the pre-existing CO_2 in the reservoirs in the monitoring program can be a challenge.*
- *Even in a relatively small area of study for the group of reefs undergoing CO_2-EOR, there is a range of geologic complexity and each reef requires a site-specific geologic model.*
- *In the depleted fields CO_2 changed phase from gas, to liquid, to super-critical as the pressure increased. Furthermore, there was a sustained decline of 2 to 4 psi/day over the 18 months post-injection period.*
- *Modeling of all these transitions across all phases of injection and decline was not possible with analytical codes. The numerical models are being used to simulate these changes. The use of synthetic models to better understand reservoir processes has been useful. It also shows the differences in reservoir response in the near-field conditions dominated by CO_2 and far-field conditions dominated by oil phase.*
- *Satellite monitoring (INSAR), combined with geomechanical modeling shows that within the margin of error, there was not perceptible change in surface elevation as reservoir pressure increased from highly depleted to above discovery pressure.*
- *Pulse Neutron Capture (PNC) logging evaluation is complicated due to presence of multiple phases (oil, gas, CO_2, brine) in the oil/gas fields and new log interpretation workflows were developed to effectively analyze these data.*
- *Fiber optic based microseismic sensor system was used to monitoring microseismic activity at lower pressure during early injection and near the end of injection, when the reef was above discovery pressure. The results are under analysis currently.*
- *Both monitoring and modeling are essential for understanding performance – imperative to be able to do much with limited data*
- *Regional characterization is helping identify new storage zones and estimate storage resources – setting stage for CCUS implementation in parts of MRCSP, outside of the large-scale test area.*
- *Results contributing to developing standards and best practices, National Risk Assessment Program (NRAP) tools, CO_2 capacity estimate tools*

Who is the project's main point-of-contact for the CSLF?

Dr. Neeraj Gupta, Principal Investigator, gupta@battelle.org, +1 614 424-3820

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Terms of Reference
CSLF Projects Interaction and Review Team

Background

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

PIRT Functions

The PIRT has the following functions:

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

Membership of the PIRT

The PIRT consists of:

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

- 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) 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.

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.

Carbon Sequestration Leadership Forum

revision date: 07 October 2010

www.cslforum.org

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.

- 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. <u>Secretariat</u>. 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. <u>Application</u>.

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. <u>Offer</u>. 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.

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

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

5. Interaction with Stakeholders

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

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Carbon Sequestration Leadership Forum

www.cslforum.org

Active and Completed CSLF Recognized Projects

(as of December 2015)

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, demonstrated, from economic and environmental criteria, the overall feasibility of coal bed methane 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. **Carbon Capture and Utilization Project / CO_2 Network Project**
Nominators: Saudi Arabia (lead) and South Africa
This is a large-scale CO_2 utilization project, including approx. 25 kilometers of pipeline infrastructure, which captures and purifies CO_2 from an existing ethylene glycol production facility located in Jubail, Saudi Arabia. More than 1,500 tonnes of CO_2 per day will be captured and transported via pipeline, for utilization mainly as a feedstock for production of methanol, urea, oxy-alcohols, and polycarbonates. Food-grade CO_2 is also a product, and the CO_2 pipeline network can be further expanded as opportunities present themselves.
Recognized by the CSLF at its Riyadh meeting, November 2015

6. **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 where the CO_2 can be stored in saline aquifers in the 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

7. **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

8. **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)

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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

9. **CGS Europe Project** ***(Completed)***
Nominators: Netherlands (lead) and Germany
This was 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 was to create a durable network of experts in CO_2 geological storage and a centralized knowledge base which will provide an independent source of information for European and international stakeholders. The CGS Europe Project provided an information pathway toward large-scale implementation of CO_2 geological storage throughout Europe. This was a three-year project, started in November 2011, and received financial support from the European Commission's 7th Framework Programme (FP7).
Recognized by the CSLF at its Beijing meeting, September 2011

10. **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

11. **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 was 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

12. **CO_2 Capture Project – Phase 3** ***(Completed)***
Nominators: United Kingdom (lead) and United States
This was a collaborative venture of seven partner companies (international oil and gas producers) plus the Electric Power Research Institute. The overall goals of the project were 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 was comprised of four areas: CO_2 Capture; Storage Monitoring & Verification; Policy & Incentives; and Communications. A fifth activity, in support of these four teams, was Economic Modeling. This third phase of the project included field demonstrations of CO_2 capture technologies and a series of

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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 continued into 2014.
Recognized by the CSLF at its Beijing meeting, September 2011

13. CO_2 Capture Project – Phase 4
Nominators: United Kingdom (lead), Canada, and United States
This multistage project is a continuance of CCP3, with the goal is to further increase understanding of existing, emerging, and breakthrough CO_2 capture technologies applied to oil and gas application scenarios (now including separation from natural gas), along with verification of safe and secure storage of CO_2 in the subsurface (now including utilization for enhanced oil recovery). The overall goal is to advance the technologies which will underpin the deployment of industrial-scale CO_2 capture and storage. Phase 4 of the project will extend through the year 2018 and includes four work streams: storage monitoring and verification; capture; policy & incentives; and communications.
Recognized by the CSLF at its Riyadh meeting, November 2015

14. CO2CRC Otway Project Stage 1 ***(Completed)***
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 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

15. CO2CRC Otway Project Stage 2
Nominators: Australia (lead) and United States
This is a continuance of the Otway Stage 1 pilot project. The goal of this second stage is to increase the knowledge base for CO_2 storage in geologic deep saline formations through seismic visualization of injected CO_2 migration and stabilization. Stage 2 of the overall project will extend into the year 2020 and will include sequestration of approx. 15,000 tonnes of CO_2. The injected plume will be observed from injection through to stabilization, to assist in the calibrating and validation of reservoir modelling's predictive capability. An anticipated outcome from the project will be improvement on methodologies for the characterization, injection and monitoring of CO_2 storage in deep saline formations.
Recognized by the CSLF at its Riyadh meeting, November 2015

16. 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

17. 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

18. 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

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

20. 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.
Recognized by the CSLF at its London meeting, October 2009

21. 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 input for developing 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

22. Dry Solid Sorbent CO_2 Capture Project

Nominators: Korea (lead), and United Kingdom

This is a pilot-scale project, located in southern Korea, which is demonstrating capture of CO_2 from a 10 megawatt power plant flue gas slipstream, using a potassium carbonate-based solid sorbent. The overall goal is to demonstrate the feasibility of dry solid sorbent capture while improving the economics (target: US$40 per ton CO_2 captured). The project will extend through most of the year 2017. There will be 180 days continuous operation each year with capture of approx. 200 tons CO_2 per day at more than 95% CO_2 purity.

Recognized by the CSLF at its Riyadh meeting, November 2015

23. Dynamis ***(Completed)***

Nominators: European Commission (lead), and Norway

This was the first phase of the multifaceted European Hypogen program, which was intended to lay the groundwork for a future advanced commercial-scale power plant with hydrogen production and CO_2 management. 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

24. 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

25. 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

26. 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

27. 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

28. 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

29. IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project ***(Completed)***
Nominators: Canada and United States (leads) and Japan
This was a monitoring activity for a large-scale project that utilizes CO_2 for enhanced oil recovery (EOR) at a Canadian oil field. The goal of the project was 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 encompassed

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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, integrated with policy research, were incorporated into a Best Practices Manual for future CO_2 Enhanced Oil Recovery projects.
Recognized by the CSLF at its Melbourne meeting, September 2004

30. 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

31. 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

32. 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

33. Jingbian CCS Project

Nominators: China (lead) and Australia
This integrated large-scale pilot project, located at a coal-to-chemicals company in the Ordos Basin of China's Shaanxi Province, is capturing CO_2 from a coal gasification plant via a commercial chilled methanol process, transporting the CO_2 by tanker truck to a nearby oil field, and utilizing the CO_2 for EOR. The overall objective is to demonstrate the viability of a commercial EOR project in China. The project includes

capture and injection of up to about 50,000 tonnes per year of CO_2. There will also be a comprehensive MMV regime for both surface and subsurface monitoring of the injected CO_2. This project is intended to be a model for efficient exploitation of Shaanxi Province's coal and oil resources, as it is estimated that more than 60% of stationary source CO_2 emissions in the province could be utilized for EOR.
Recognized by the CSLF at its Regina meeting, June 2015

34. 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

35. 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

36. 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

37. 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

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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

38. Norcem CO_2 Capture Project
Nominators: Norway (lead) and Germany
This project, located in southern Norway at a commercial cement production facility, is testing four different post-combustion CO_2 capture technologies at scales ranging from very small pilot to small pilot. Technologies being tested are a 1st generation amine-based solvent, a 3rd generation solid sorbent, 3rd generation gas separation membranes, and a 2nd generation regenerative calcium cycle, all using flue gas from the cement production facility. Objectives of the project are to determine the long-term attributes and performance of these technologies in a real-world industrial setting and to learn the suitability of such technologies for implementation in modern cement kiln systems. Important focus areas include CO_2 capture rates, energy consumption, impact of flue gas impurities, space requirements, and projected CO_2 capture costs.
Recognized by the CSLF at its Warsaw meeting, October 2014

39. Oxy-Combustion of Heavy Liquid Fuels Project
Nominators: Saudi Arabia (lead) and United States
This is a large pilot project (approx. 30-60 megawatts in scale), located in Dhahran, Saudi Arabia whose goals are to investigate the performance of oxy-fuel combustion technology when firing difficult-to-burn liquid fuels such as asphalt, and to assess the operation and performance of the CO_2 capture unit of the project. The project will build on knowledge from a 15 megawatt oxy-combustion small pilot that was operated in the United States by Alstom. An anticipated outcome from the project will be identifying and overcoming scale-up and bottleneck issues as a step toward future commercialization of the technology.
Recognized by the CSLF at its Riyadh meeting, November 2015

40. 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

41. 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

42. 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

43. 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

44. SaskPower Integrated CCS Demonstration Project at Boundary Dam Unit 3
Nominators: Canada (lead) and the United States
This large-scale project, located in the southeastern corner of Saskatchewan Province in Canada, is the first application of full stream CO_2 recovery from flue gas of a commercial 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

45. 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

46. 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

47. 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

48. 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

49. 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

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

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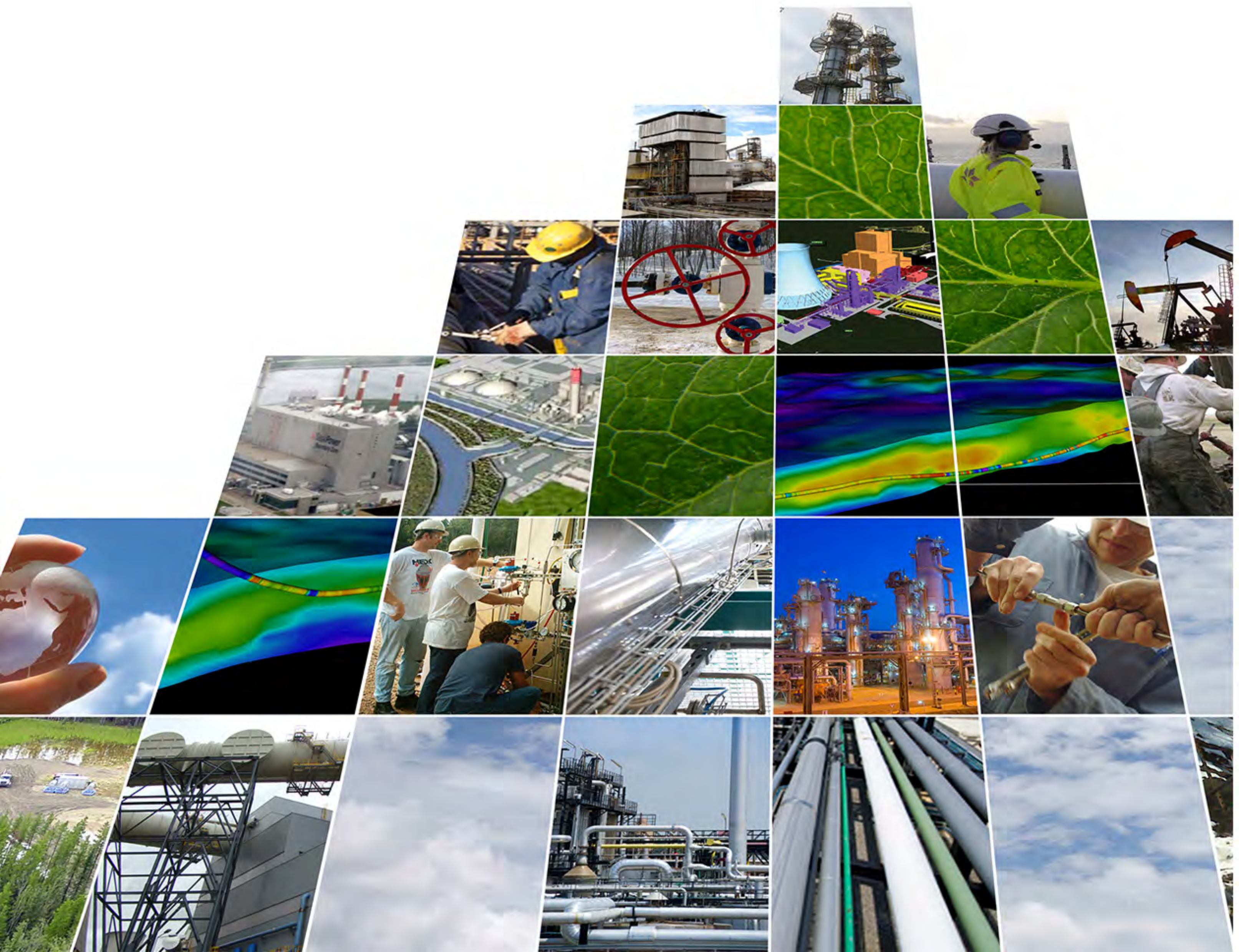
2013

Carbon Sequestration

TECHNOLOGY ROADMAP

carbon sequestration leadership forum



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* *by 2050. This requires rapid deployment of CCS and this is a significant challenge since there are no large-scale CCS demonstrations in power generation and few in industry"*.

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

3. Assessment of Present Situation

3.1. Implementation

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

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

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

3.2. Capture

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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.

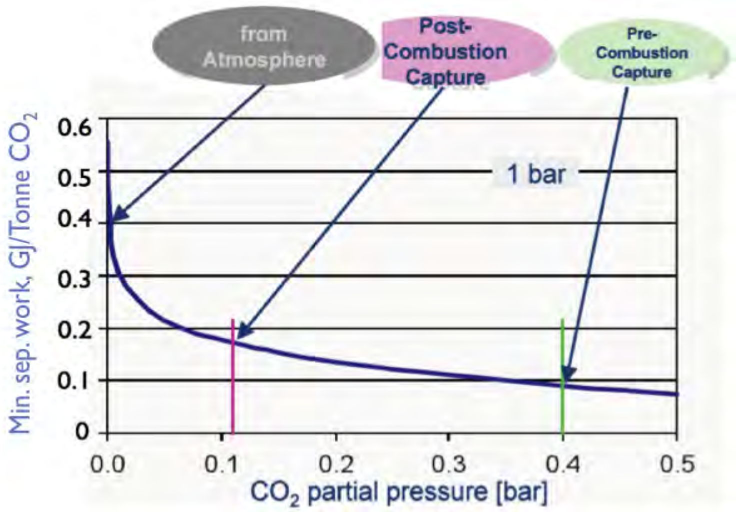

Figure 1: Theoretical minimum separation work of CO_2 from a flue gas depending on the partial pressure of CO_2 [modified from Bolland et al., 2006]

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.

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

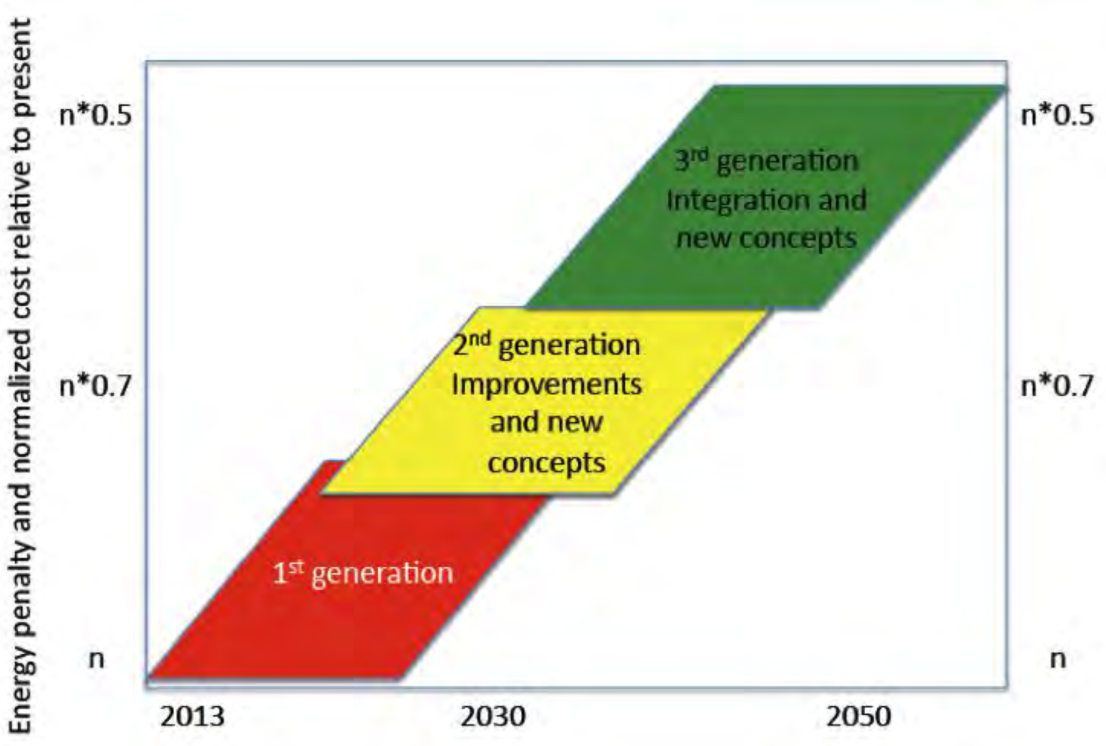

Figure 2: Priorities for CCS technology development. The energy penalty and normalized costs are shown in relation to the present level (n), i.e. equivalent to reduction by 30% in 2030 and 50% towards 2050.

4.2. Transport

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

4.2.1. Recommendation 3: CO_2 Transport

Towards 2020:

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

4.3. Storage

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

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

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

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

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

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

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

Other issues that need RD&D are:

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

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

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

4.3.1. Recommendation 4: Large-Scale CO_2 Storage

Towards 2020:

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

Towards 2030:

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

Towards 2050:

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

4.3.2. Recommendation 5: Monitoring and Mitigation/Remediation

Towards 2020:

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

Towards 2030:

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

4.3.3 Recommendation 6: Understanding the Storage Reservoirs

Towards 2020:

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

4.4. Infrastructure and the Integrated CCS Chain

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

Other RD&D needs include:

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

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

4.4.1. Recommendation 7: Infrastructure

Towards 2020:

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

Towards 2030:

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

4.5. Utilization

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

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

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

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

4.5.1. Recommendation 8: CO_2 Utilization

Towards 2020:

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

5. Priority Actions Recommended for Implementation by Policy Makers

Towards 2020 nations should work together to:

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

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

<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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