carbon sequestration leadership forum

2016 CSLF Mid-Year Meeting

London, United Kingdom

June 27-30 2016

MEETING DOCUMENTS BOOK

Carbon Sequestration Leadership Forum

www.cslforum.org

2016 CSLF MID-YEAR MEETING DOCUMENTS BOOK

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Carbon Sequestration Leadership Forum

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2016 CSLF Mid-Year Meeting Overall Schedule

London, United Kingdom

June 27-30, 2016

	Monday, June 27 Imperial College	**Tuesday, June 28** Emmanuel Centre	**Wednesday, June 29** Emmanuel Centre	**Thursday, June 30** Emmanuel Centre
Morning	CCS Academic Council (note: closed meeting)	CSLF Technical Group	Capacity Building Council (note: closed meeting, prior to Workshop) Workshop	CSLF Policy Group
Afternoon	CCS Academic Council (*continues*) Projects Interaction and Review Team (PIRT)	CSLF Technical Group (*continues*)	Workshop (*continues*)	CSLF Policy Group (*continues*)
Evening	Lab & Pilot Plant Tour Dinner		CCSA Reception	

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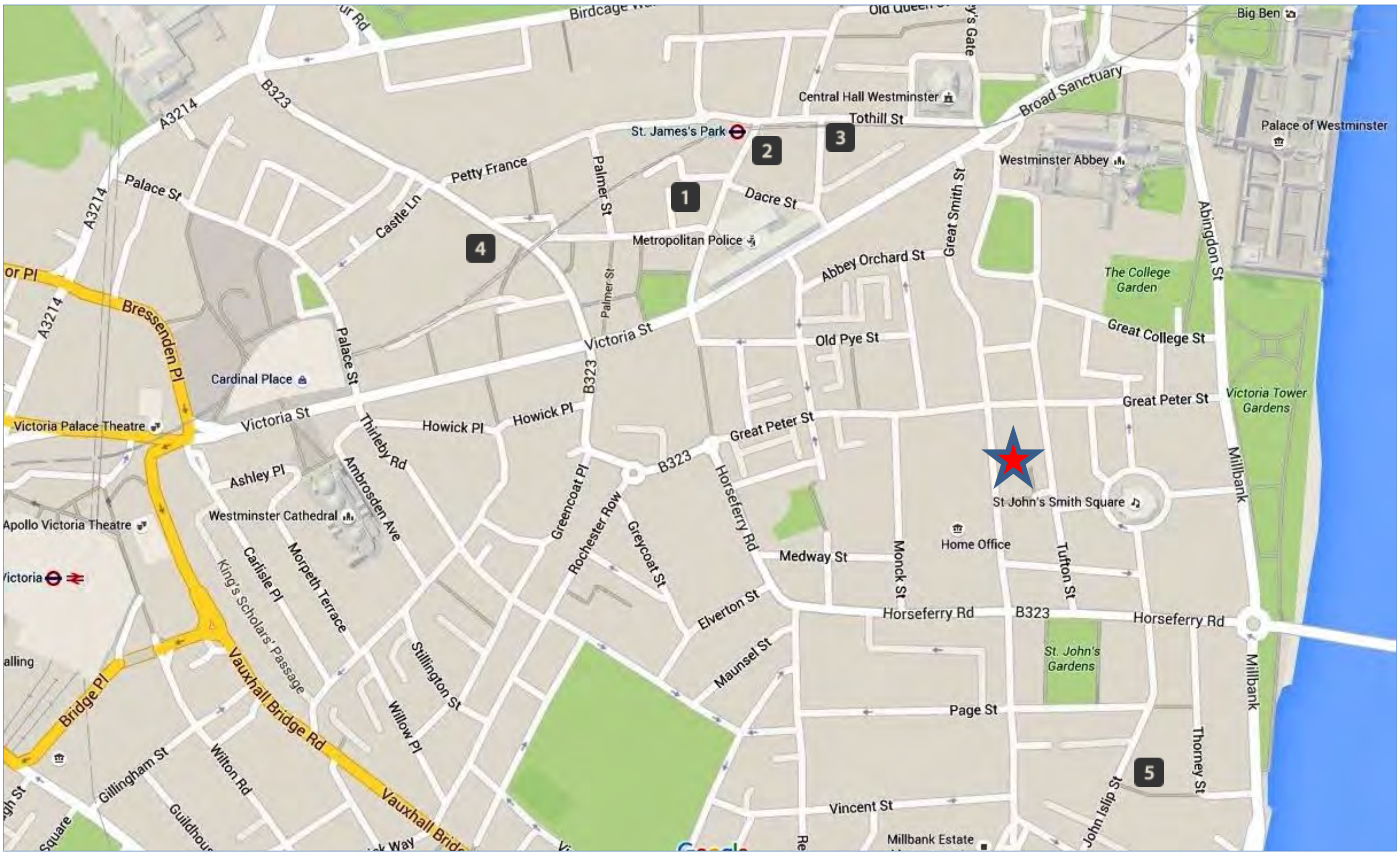
Meeting Venue Information

The 2016 CSLF Mid-Year Meeting will be in **London, United Kingdom** from Monday, June 27 through Thursday, June 30. Meeting venues are as follows:

PIRT Task Force meeting (on June 27): **Imperial College (Main Entrance)**, Exhibition Road
Other meetings: **Emmanuel Centre**, 9-23 Marsham Street ★

Hotels proximate to the Emmanuel Centre include:

1. **St. Ermin's Marriott Hotel** (*2 Caxton Street; approx. 0.6 km walk*)
2. **Conrad London St. James** (*22-28 Broadway; approx. 0.7 km walk*)
3. **Sanctuary House Hotel** (*33 Tothill Street; approx. 0.6 km walk*)
4. **St. James Court** (*45-51 Buckingham Gate; approx. 0.8 km walk*)
5. **Doubletree Hotel Westminster** (*30 John Islip Street; approx. 0.5 km walk*)



Next two pages:

- Map showing area around Emmanuel Centre
- Map of Imperial College (Main Entrance located between Building 17 and Building 28)

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Emmanuel Centre
Supporting Your Success

Emmanuel Centre
9-23 Marsham Street, Westminster, London SW1P 3DW

Tel: 020 7222 9191 Fax: 020 7233 1922
www.emmanuelcentre.com

How to find us

By Underground
St. James Park - Circle Line, District Line.
Approx. 7 minutes walk away (.30mile).
Westminster - Jubilee Line, Circle Line & District Line.
Approx. 9 minutes walk away (.6mile).
Victoria - Circle Line, District Line & Victoria Line.
Approx. 15 minutes walk away (1mile)
Pimlico - Victoria Line.
Approx. 5 minutes walk away (.66mile).

By Rail
Victoria Railway Station - Aprox. 15 minutes walk away (1mile).
Charing Cross Railway Station - Approx 19 minutes walk away (1.5mile).

By Bus
Nearest bus stop is in Marsham Street and the bus number is 88.
Numbers 87, 3 along Millbank.
Numbers 11, 24, 211, 148 travelling along Victoria Street.
Numbers 507 along Horseferry Road.
Numbers 53, 453, 12, 159 for Whitehall.

For more information regarding transport around London check their website www.tfl.gov.uk

Car Parks
Abingdon Masterpark in Great College Street and Medway Street NCP both within 3 minutes walk away.

Imperial College London

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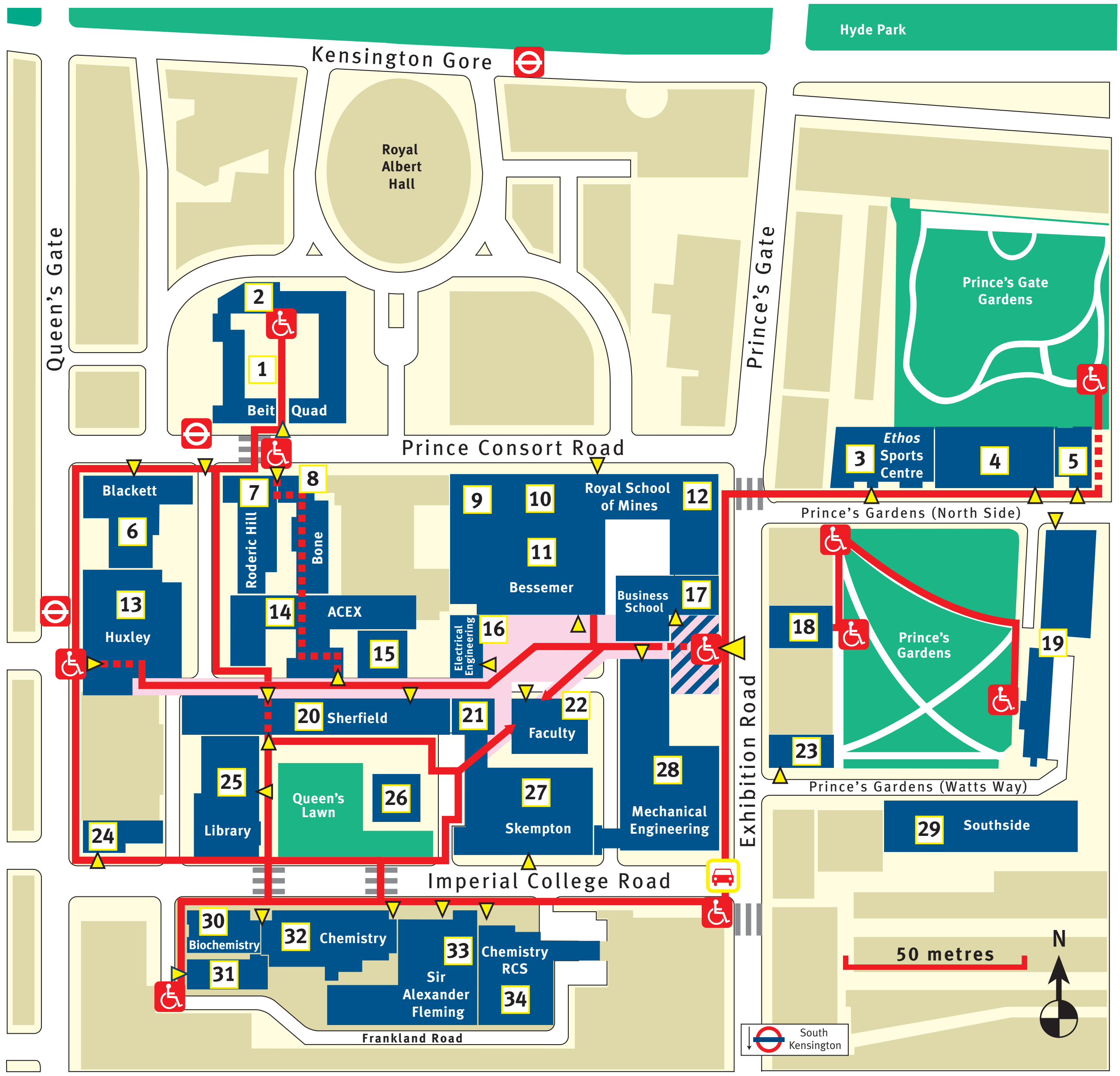
South Kensington Campus



Main walkway

Main entrance

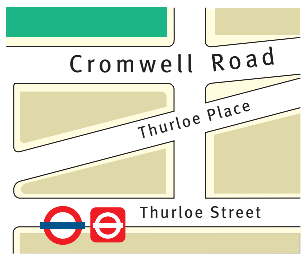
Accessible route

South Kensington Underground

Bus stops

Building entrances

Vehicle entrance



Buildings where wheelchair access is not possible at this time

1	Beit Quadrangle
2	Imperial College Union
3	*Ethos* Sports Centre
4	Prince's Gdns, North Side Garden Hall
5	Weeks Hall
6	Blackett Laboratory
7	Roderic Hill Building
8	Bone Building
9	Royal School of Mines (no wheelchair access)
10	Aston Webb
11	Bessemer Building
12	Goldsmiths Building
13	Huxley Building
14	ACE Extension
15	William Penney Laboratory (no wheelchair access)
16	Electrical Engineering
17	Business School
18	53 Prince's Gate
19	Eastside (under construction)
20	Sherfield Building Student Hub Conference Office
21	Grantham Institute for Climate Change
22	Faculty Building
23	58 Prince's Gate (no wheelchair access)
24	170 Queen's Gate (no wheelchair access)
25	Imperial College and Science Museum Libraries
26	Queen's Tower
27	Skempton Building
28	Mechanical Engineering Building
29	Southside
30	Biochemistry Building
31	Flowers Building
32	Chemistry Building
33	Sir Alexander Fleming Building
34	Chemistry RCS

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Draft: 21 June 2016
Prepared by CSLF Secretariat

Agenda

CSLF PROJECTS INTERACTION AND REVIEW TEAM (PIRT)

Imperial College
Exhibition Road
London, United Kingdom

27 June 2016

***Note*: Meeting will be held in Chemical Engineering School Building (Building #15 on Imperial College map).**

14:00-16:00

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 Riyadh PIRT Meeting**
   Andrew Barrett, PIRT Chair, Australia

5. **Report from Secretariat**
   - Review of Riyadh PIRT Meeting
   - Update on CSLF Recognized Projects

   Richard Lynch, CSLF Secretariat

6. **Current PIRT Activities**
   - TRM Update

   Andrew Barrett, PIRT Chair, Australia

7. **Future PIRT Activities**
   - Technology Workshops
   - Finding Ways to Better Engage Project Sponsors

   Andrew Barrett, PIRT Chair, Australia

8. **Open Discussion on Possible New Technical Group Activities** CSLF-T-2016-04
   Åse Slagtern, Technical Group Chair, Norway
   PIRT Delegates and Meeting Attendees

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

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

11. **Closing Comments / Adjourn**
    Andrew Barrett, PIRT Chair, Australia

Carbon Sequestration Leadership Forum

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CSLF-T-2016-02
Draft: 20 June 2016
Prepared by CSLF Secretariat

DRAFT AGENDA
CSLF Technical Group Meeting

Emmanuel Centre
9-23 Marsham Street, Westminster
London, United Kingdom

28 June 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**
Brian Allison, Department of Energy and Climate Change, United Kingdom

3. **Introduction of Delegates**
Delegates

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

5. **Review and Approval of Minutes from Riyadh Meeting** CSLF-T-2016-01
Åse Slagtern, Technical Group Chair, Norway

6. **Report from Secretariat**
   - Highlights from November 2015 Ministerial Meeting
   - Review of Riyadh Meeting Action Items

Richard Lynch, CSLF Secretariat

7. **Host Country CCS Presentation**
Will Lochhead, Department of Energy and Climate Change, United Kingdom
Brian Allison, Department of Energy and Climate Change, United Kingdom

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

10:30-10:45 Refreshment Break

10:45-12:00 Continuation of Meeting

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

10. **Progress Report on next CSLF Technology Roadmap** CSLF-T-2016-03
Andrew Barrett, Working Group Chair, Australia

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

12:00-13:30 Lunch

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13:30-15:30 Continuation of Meeting

12. Report from Bioenergy with CCS Task Force
Mark Ackiewicz, Task Force Chair, United States

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

14. Review of Technical Group Action Plan and Possible New Technical Group Activities CSLF-T-2016-04
Åse Slagtern, Technical Group Chair, Norway

15. Update on the ISO TC265 Committee
Tim Dixon, IEAGHG

16. Report on IEAGHG-CSLF Life Cycle Assessment Workshop
Jazmin Kemper, IEAGHG

17. Report on CSLF Offshore Storage Workshop
Tim Dixon, IEAGHG

15:30-15:45 Refreshment Break

15:45-17:30 Continuation of Meeting

18. Otway Stage 2C Project Update
Max Watson, CO2CRC, Australia

19. Overview of the QICS Project: a Deep-Water Sub-Seabed Controlled Release Experiment
Stephen Widdicombe, Plymouth Marine Laboratory, United Kingdom

20. Evaluation of Barriers to CO_2 Geological Storage Assessments
James Craig, IEAGHG

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

22. Open Discussion and New Business
Delegates

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

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

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Carbon Capture & Storage Association

CCS Post-Paris: Realising Global Ambitions

CSLF Workshop in association with the Carbon Capture and Storage Association

Wednesday 29th June
Upper Hall, Emmanuel Centre, Marsham Street, London, SW1P 3DW

To register, please visit:
http://www.cslforum.org/meetings/london2016/premeeting.html

#CCSPostParis

Time	Item
10:30 – 11:00	Arrivals and refreshments
11:00 – 11:45	Session 1: The role of CCS post-Paris *Chaired by Luke Warren (Chief Executive, CCSA)* **What role for CCS following COP21?** *(Philippe Benoit – Head of Energy and Environment Division, International Energy Agency)* **The global carbon budget, fossil fuel assets and the role of CCS** *(Myles Allen – Leader, Climate Research Programme, University of Oxford)*
11:45 – 12:15	Keynote: **Sleipner – 20 years of successful storage operations and key learning for future projects** *(Olav Skalmeraas – Vice President, Statoil)*
12:15 – 13:15	Lunch
13:15 – 14:15	Session 2: Preparing for deployment *Chaired by Brian Allison (Department of Energy and Climate Change, UK)* **A global perspective of the geological CO_2 storage resource potential** *(Andrew Purvis – General Manager EMEA, GCCSI)* **Conclusions of the UK Storage Appraisal Programme** *(Den Gammer – Programme Manager CCS, Energy Technologies Institute)* **Carbon Capture Readiness: Experiences in implementing capture readiness in the EU** *(Maria Velkova, Policy Officer - Low Carbon Technologies Policies and Measures, DG Climate Action, European Commission; and Neal Mehta (Managing Consultant, ICF International)*

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Time	Item
14:15 – 15:00	<u>Session 3: Hubs, clusters and sharing infrastructure</u> *Chaired by Kirsty Anderson (Principal Manager Public Engagement, GCCSI)* **The North Sea Basin Task Force: Catalysing "Europe's Silicon Valley"** *Representatives of the North Sea Basin Task Force:* • *Almut Fischer – Federal Ministry for Economic Affairs & Energy, Germany* • *Stig Svenningsen – Norwegian Ministry of Petroleum and Energy* To be joined in a panel discussion by: • Andy Read (Director, ROAD) • Sarah Tennison (Tees Valley Combined Authority)
15:00 – 15:30	Refreshment break
15:30 – 17:15	<u>Session 4: Fresh perspectives on CCS</u> *Chaired by Graeme Sweeney (Chair, Zero Emission Platform)* **Lessons Learned from the UK CCS Commercialisation Programme** *(Theo Mitchell – Policy Manager, CCSA)* **The case for a 'market maker' and a business model for CO_2 storage** *(Owain Tucker – Co-Chair, Zero Emission Platform Working Group on Transport and Storage; Global Deployment Lead CCS and CCUS, Shell)* **The US DOE/EERC Brine Extraction and Storage Test (BEST): Phase One lessons learned and Phase Two plans** *(Edward Steadman – Vice President for Research, University of North Dakota's Energy and Environmental Research Center)* **Beyond pipelines: The case for shipping CO_2** *(John Kristian Økland – Project Manager, Gassco)* **CCS, Heat and Hydrogen: Decarbonising the Leeds city-region** *(Dan Sadler – Head of Investment Planning and Major Projects, Northern Gas Networks)*
17:15 – 17:30	<u>Session 5: What can the CSLF do? Summary and Next Steps</u> • Jarad Daniels (CSLF Policy Group Chair, U.S. Department of Energy) • Åse Slagtern (CSLF Technical Group Chair, Research Council of Norway) • Luke Warren (Chief Executive, CCSA)
17:30 – 19:00	**CCSA Annual Reception**, including remarks from: • Baroness Helen Liddell (Honorary President, CCSA)

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CSLF-P-2016-02
Draft: 21 June 2016
Prepared by CSLF Secretariat

DRAFT AGENDA
CSLF Policy Group Meeting

Emmanuel Centre
9-23 Marsham Street, Westminster
London, United Kingdom
Thursday, June 30, 2016

08:00-09:00 Meeting Registration

09:00-10:15 Policy Group Meeting

1. **Welcome and Opening Statement**
   Jarad Daniels, Policy Group Chair, United States
2. **Meeting Host's Welcome**
   Brian Allison, Department of Energy and Climate Change, United Kingdom
3. **Introduction of Delegates**
   Delegates
4. **Adoption of Agenda**
   Jarad Daniels, Policy Group Chair, United States
5. **Review and Approval of Minutes from Riyadh Meeting** CSLF-P-2016-01
   Jarad Daniels, Policy Group Chair, United States
6. **Review of Riyadh Meeting Action Items**
   Stephanie Duran, CSLF Secretariat
7. **Outcomes from the 2015 United Nations Climate Change Conference (COP21)**
   John Gale, IEA Greenhouse Gas R&D Programme
8. **Report from CSLF Technical Group**
   Åse Slagtern, Technical Group Chair, Norway
9. **Summary of CSLF Workshop**
   Luke Warren, Carbon Capture & Storage Association

10:15-10:30 Refreshment Break

10:30-12:00 Continuation of Meeting

10. **Report from the Communications Task Force**
    Hamoud AlOtaibi, Saudi Arabia
11. **Report from the Global Collaboration on Large-Scale CCS Projects Task Force**
    Jiutian Zhang, China
    Jarad Daniels, Policy Group Chair, United States
12. **Report from the Supporting Development of 2nd and 3rd Generation CCS Technologies Task Force**
    Kathryn Gagnon, Canada

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12:00-13:00 Lunch

13:00-15:00 Continuation of Meeting

13. **Report from the Financing for CCS Projects Task Force**
    Bernard Frois, France

14. **Report from the Capacity Building Governing Council**
    William Christensen, Norway

    a. **Report from CSLF Capacity Building Event: International Academic CCS Summit**
       Philippa Parmiter, Scottish Carbon Capture & Storage

    b. **Report from CSLF Capacity Building Event: Offshore Storage Workshop**
       Tony Surridge, South Africa

15. **Report from the CCS in the Academic Council**
    Ed Rubin, Carnegie Mellon University

16. **International Energy Agency CCS Activities Update**
    Tristan Stanley, International Energy Agency

17. **Global CCS Institute Update**
    Andrew Purvis, Global CCS Institute

18. **Reclaiming CCS in the Public Interest: Perspective from Environmental Non-Governmental Organization (NGO) Community**
    Chris Littlecott, E3G

19. **CO_2 Market Makers for Strategic European CCS Hubs & Clusters**
    Keith Whiriskey, The Bellona Foundation

15:00-15:15 Refreshment Break

15:15-16:30 Continuation of Meeting

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

21. **CSLF Website Update**
    Stephanie Duran, CSLF Secretariat

22. **Mission Innovation / Clean Energy Ministerial**
    Jarad Daniels, Policy Group Chair, United States
    Delegates

23. **Upcoming Election of Policy Group Vice Chairs**
    Stephanie Duran, CSLF Secretariat

24. **Future CSLF Meetings**
    Stephanie Duran, CSLF Secretariat

25. **Open Discussion and New Business**
    Delegates

26. **Action Items and Next Steps**
    Stephanie Duran, CSLF Secretariat

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

Carbon Sequestration Leadership Forum
www.cslforum.org
CSLF-P-2016-01
Draft: 14 June 2016
Prepared by CSLF Secretariat

Draft Minutes of the Policy Group Meeting
Riyadh, Saudi Arabia
Tuesday, November 3, 2015

LIST OF ATTENDEES

Chair	Christopher Smith, United States

Policy Group Delegates

Australia:	Josh Cosgrave, Andrew Barrett
Brazil:	José Renato
Canada:	Geoff Murphy
China:	Xian Zhang (*Vice Chair*), Qiang Liu
European Commission:	Jeroen Schuppers
France:	Bernard Frois
Germany:	Thomas Gäckle, Almut Fischer
Italy:	Sergio Persoglia
Japan:	Takashi Kawabata, Ryozo Tanaka
Korea:	Byeong Yeol Jeon, Sang Joo Baek
Mexico:	Rubén Beltrán-Palafox
Netherlands:	Paul Van Slobbe
Norway:	William Christensen, Fredrik Netland
Poland:	Marek Malarski
Romania:	Daniela Barbu, Mircea Toader
Saudi Arabia:	Khalid Abuleif (*Vice Chair*), Hamoud AlOtaibi
South Africa:	Gina Downes, Tony Surridge
United Arab Emirates:	Arafat Saleh Al-Yafei, Khaled Al-Yaqoubi
United Kingdom:	Tony Ripley (*Vice Chair*), Brian Allison
United States:	Julio Friedmann, Mark Ackiewicz

Representatives of Allied Organizations

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

CSLF Secretariat

Jarad Daniels, Richard Lynch, Adam Wong

Invited Speakers, Distinguished Guests, and Observers

Australia:	Max Watson
Canada:	Eddy Chui, Michael Monea
Chinese Taipei:	Vincent S.N. Chen, Yi-Shun Chen, Shoung Ouyang
Czech Republic:	Pavel Kavina
France:	Didier Bonijoly
Korea:	Chang Keun Yi, Chong Kul Ryu
Netherlands:	Hans Schoenmakers

Norway:	Trygve Riis, Lars Ingolf Eide, Åse Slagtern
Qatar:	Saif Al-Naimi
Romania:	Andrei Gerea
Saudi Arabia:	Saeed Alalloush, Ahmed Aleidan, Ahmed Al-Fahdah, Abdelrahman Al-Gwaiz, Fahad Almuhaish, Wolfgang Heidug, Hatem Mohiey, Muhammad Zahid
United Kingdom:	David Hone
United States:	Mihaela Carstei, Ed Dodge, Stephanie Duran, Scott McDonald, Tip Meckel, Michael Moore, Barry Worthington

1. Welcome and Opening Statement

The Policy Group Chair, Christopher Smith, called the meeting to order and thanked the Ministry of Petroleum and Mineral Resources of Saudi Arabia for hosting. He acknowledged the hard work of the Policy Group, Technical Group, Stakeholders, and CSLF Secretariat. Mr. Smith stated that globally, progress has been made to advance carbon capture and storage (CCS) since the last CSLF Ministerial in 2013. Mr. Smith made note of the upcoming 2015 United Nations Climate Change Conference (COP21), and stressed that CSLF collaboration will become even more important.

2. Meeting Host's Welcome

Hamoud AlOtaibi, Advisor to the Office of Climate Change at Saudi Arabia's Ministry of Petroleum and Mineral Resources, welcomed the meeting attendees to the Kingdom of Saudi Arabia. Mr. AlOtaibi stated that the 6th CSLF Ministerial is the largest and most high-profile meeting, and Saudi Arabia is honored to be hosting a large number of Ministers and high-level officials. Mr. AlOtaibi also welcomed the non-CSLF members to the meeting, and encouraged their full participation in the discussion. With COP21 occurring later in the month, Mr. AlOtaibi expressed the need to increase the discussion regarding policy issues on CCS.

3. Introduction of Delegates

Policy Group delegates introduced themselves. Nineteen of the twenty-three CSLF Members were present, including representatives from Australia, Brazil, Canada, China, European Commission, France, Germany, Italy, Japan, Korea, Mexico, Netherlands, Norway, Poland, Saudi Arabia, South Africa, the United Arab Emirates, the United Kingdom, and the United States. Observers representing the Global CCS Institute, International Energy Agency, the IEA Greenhouse Gas R&D Programme (IEAGHG), Australia, Canada, Chinese Taipei, Czech Republic, France, Korea, Netherlands, Norway, Qatar, Romania, Saudi Arabia, the United Kingdom, and the United States were also present.

4. Adoption of Agenda

The Agenda was adopted without change.

5. Review and Approval of Minutes from Regina Meeting

The Minutes from the CSLF Policy Group Meeting on June 19, 2015, in Regina, Saskatchewan, Canada were approved without change.

6. Review of Regina Meeting Action Items

Jarad Daniels, Director of the CSLF Secretariat, provided a brief summary of the action items from the CSLF Policy Group Meeting on June 19, 2015, in Regina, Saskatchewan, Canada. All action items have been completed or were to be completed during the day's meeting.

7. Consideration of Applications for CSLF Membership

Andrei Gerea, Minister of Energy, Small and Medium–Sized Enterprises, and the Business Environment, Romania, presented Romania's application for CSLF Membership. Romania is in an enviable position with regard to energy. Romania is the third most energy independent country in the European Union. The country has a long standing production of coal and oil and gas, stretching back more than 150 years. Romania is rapidly becoming a regional leader in tackling climate change and looking into the future for appropriate technologies to achieve these goals. As part of the national priorities for energy and climate change, CCS plays a key role in ensuring Romania's ability to maintain a balanced energy mix and create a competitive economy while it pursues ambitious decarbonization goals.

After the remarks by Minister Gerea, the Policy Group voted to approve and welcome Romania as a CSLF member.

8. Report from CSLF Technical Group

The Technical Group Chair, Trygve Riis, provided a summary of the previous day's meeting. The Technical Group voted to recommend the following five projects that had been nominated 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

Key Technical Group deliverables for the CSLF Ministerial Conference include:

- Technology Roadmap (TRM) Interim Report
- Report on Development of 2^{nd} and 3^{rd} Generation CO_2 Capture Technologies
- Key Messages from the CSLF "Lessons Learned from Large-Scale CCS" Workshop
- Messages and Recommendations from CSLF Technical Group

The Technical Group reached a consensus on the following items:

- Form a working group to determine the way forward for future Technology Road Map update activities. Members of the working group are Australia (Chair), Norway, South Africa, the United Kingdom, the United States, the IEAGHG, and the CSLF Secretariat.
- Form a new Task Force on Offshore CO_2-EOR, to be chaired by Norway. Other members are Canada, China, the United States, and the IEAGHG.
- Form a new Task Force on Bioenergy with CCS, to be chaired by the United States. Other members are Italy, Norway, and the IEAGHG.
- Form a new Task Force on Improved Pore Space Utilization, to be co-chaired by Australia and the United Kingdom. Other members are France, Japan, the United Arab Emirates, and the IEAGHG.
- The Technical Group is temporarily postponing decisions on forming new task forces in the areas of Geo-steering / Pressure Management Techniques and Industrial CCS. These will be taken up again at the next meeting
- Norway was re-elected as Technical Group Chair for a period lasting three years

- Australia, Canada, and South Africa were re-elected as Technical Group Vice Chairs, for a period lasting three years

After the update from Mr. Riis, the Policy Group voted to approve the five nominated projects for CSLF recognition.

9. Report from the CCS in the Academic Community Task Force

Wolfgang Heidug, Advisor to the King Abdullah Petroleum Studies and Research Center (KAPSARC), reported from the CCS in the Academic Community Task Force. Formed in 2008 at the Policy Group Meeting in San Francisco, this Task Force's mission is to identify and engage academic programs on CCS throughout the world and to help determine the path forward for the CSLF. More recently, the Task Force conducted a baseline survey of CCS academic research programs, current international collaborations, student exchanges, summer schools, and CCS networks. Additionally, the Task Force has developed an Initial Plan of Action. After the presentation, Australia expressed an interest in contributing to the expanded work program reports of the Task Force.

10. Report from the CSLF Capacity Building Governing Council

The Capacity Building Governing Council Chair, William Christensen, 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. As of now, US $1,984,409 has been committed for 14 approved projects in 5 countries. Of the 14 approved projects, 10 have been completed and 4 are to be negotiated or revised. The funds currently available for allocation are US $924,072.80 (AU $1,180,169.60). A new call for project proposals was distributed after the CSLF Policy Group Meeting on June 19, 2015, in Regina, Saskatchewan, Canada, and the Governing Council welcomes submissions for the remaining available funds. New CSLF Members are encouraged to submit project proposals for funds.

11. Discussion of Committee Work Plan Status:

a. Financing for CCS Projects

Task Force Chair Bernard Frois spoke on the Financing for CCS Projects work. There is an increased interest in CCS, due to the fact that several operating plants now exist employing a range of technologies that has started to create the "precedent" base the financial world needs to get comfortable with the industry. CCS is recognized as a clean energy mechanism, as organizations such as the IEA has identified CCS as one of the most important technologies to mitigate temperature increase. A large number of projects around the world demonstrate that the technology works with a growing recognition of the economic impact (EOR, water, chemical products) of CCS projects. Success stories have encouraged investments (SaskPower et al.) and a broad suite of financing mechanisms exists. However, short and long-term funding mechanisms are still needed. CCS will require:

- Long-term signal of support/need for CCS
- Policy parity; a level playing field with other low carbon technologies
- Short term support to build and operate CCS demonstration plants

David Hone, Chief Climate Change Adviser, Shell International Ltd., presented on behalf of the World Business Council for Sustainable Development (WBCSD) about the CCS component of the Low Carbon Technology Partnerships Initiative (LCTPI). Within the

CCS work, the LCTIP is developing an idea for financing next generation CCS projects. CCS currently demands either a significant carbon price in the market, or a major grant or capital injection from government with a modest carbon price in the market. Indications are that this does not represent a sustainable model going forward, as there is a resistance to high carbon prices due to competitiveness concerns and/or higher energy prices, along with fiscal tightness in many countries that may mean less availability of grants.

WBCSD has put together new idea for funding CCS, using a mechanism that rewards the storage of CO_2. This can be done by the creation of a credit that represents one tonne of CO_2 stored (the Zero Emission Credit or ZEC), while near term demand is created through an investment fund and long term demand comes through national compliance based systems. This prototype fund may drive early demand and act as a buyer of ZECs and is not directly involved in projects. This fund is modelled after the World Bank Prototype Carbon Fund (2000-2015) and would involve many smaller investors (companies, governments, foundations, individuals) rather than large single grants.

It was agreed that the group will reconvene another roundtable meeting after COP21 to discuss opportunities for the CSLF to advance financing of CCS projects.

b. Supporting Development of 2nd and 3rd Generation CCS Technologies

Task Force Co-Chair Geoff Murphy provided an update on the Supporting Development of 2nd and 3rd Generation CCS Technologies work. At the CSLF Policy Group Meeting on June 19, 2015, in Regina, Saskatchewan, Canada, existing and potential policy and funding mechanisms to drive RD&D and reduce costs were reported, and Canada noted that a consultant had interviewed over 35 CCS stakeholders. The conclusions from the technical literature review identified approximately 30 groupings of emerging technologies. Most of these emerging technologies are 3rd generation (i.e. unlikely to reach large scale implementation before 2030), while a minority was classified as 2nd generation (i.e. ready for large scale implementation by 2020 – 2025). The review also identified 11 test facilities around the world to speed up the development of emerging technologies, the majority of which are designed for post-combustion capture of CO_2. The review also identified various barriers, such as lack of market, high costs, technical and operational challenges, insufficient test sites in key geographies and sectors, and storage availability and lack of clear regulations. The review found high priority mechanisms identified in the interviews to overcome each barrier. All of these findings were reported in a background document available for the meeting. The group found seven recommendations for CSLF Ministerial Consideration. In order to deliver, enhanced networks, expanded online tools, and enhanced research cooperation should all be utilized. It was agreed that the CSLF Secretariat would work with Canada and Norway to implement these positions and opportunities onto the CSLF website, in order to open it up to other members.

c. Global Collaboration on Large-Scale CCS Projects

Jarad Daniels delivered an overview on the work of the Large-Scale CCS Projects efforts. The CSLF is well-positioned to facilitate global collaboration efforts for large- scale CCS projects, whether as new projects or by adding additional functionality and value to existing or planned commercial projects. Furthermore, as many of the recently deployed large-scale CCS projects are focused on storage via enhanced oil recovery (EOR), the needs of large saline formation storage has remained underserved. Mark Ackiewicz provided an update on the work that the United States Department of Energy (US DOE) and Shell’s Quest Project was doing to facilitate these efforts. The CSLF will form the

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Large-Scale Saline Storage Project Network to serve two purposes: 1) facilitate collaborative testing of advanced technologies at large-scale saline storage sites, and 2) form a global network of large-scale injection sites that can share best practices, operational experience, and key learnings. As a first step in this effort, US DOE and the Shell Quest CCS Project have collaborated over the past year on identifying opportunities to field test advanced technologies funded through the US DOE at the Quest Project in Alberta, Canada. It was stressed that commitment by all parties, both governments and projects, is key for this work. Delegates and representatives from various projects spoke on how the CSLF can leverage opportunities for future collaboration, as together the projects can help to lower costs and advance CCS, and also demonstrate the policy side to CCS. It was agreed that the efforts of this group will continue to find a way to leverage large-scale CCS projects.

d. Communications

Hamoud AlOtaibi led the update from the CSLF Communications Task Force. The Task Force has looked at consultants outside the CSLF to deliver key CCS messages from communications experts. One of these consultants, Ed Dodge, then spoke on a CSLF Communications Strategy. This strategy should identify a vision, message, messenger, audience, and medium. Near and long-term goals should be needed, with the ultimate goal of including CCS in the clean energy vision to the public. CCS should be considered part of the portfolio of clean energy solutions alongside efficiency and renewables. CCS can be a component of advanced refining to produce clean fuels the world is increasingly demanding, and it should be noted that CO_2 is useful, and is not just burying the garbage.

After a discussion among the delegates, it was determined that the communications strategy from the CSLF needs to further investigate what message it is sending, how it sends this message, and who is receiving the message.

12. IEA CCS Activities Update

Tristan Stanley, Energy Analyst at the International Energy Agency (IEA), presented on how CCS fits into the global energy picture, particularly in the context of reducing global emissions. The IEA's recent "Energy Technology Perspectives 2015" (ETP 2015) maps a process for governments to achieve climate change goals. In all scenarios, from 2-6 degrees (2Ds-6Ds), a portfolio of technologies is required to get to emission reduction goals. In the 2Ds, CCS is important in both electricity and industry, and over two-thirds of total CO_2 captured and stored is in non-OECD countries. In the 2DS, by 2050, 5 - 6 Gt of CO_2 per year are captured and stored in all sectors. The ETP 2015 also noted that CCS deployment has begun in "sweet spots," and that "learning-by-doing" is now also underway for CCS in power generation. The IEA is also looking at storage of CO_2 through enhanced oil recovery (EOR), and has analyzed three EOR operational models: Conventional EOR+, Advanced EOR+, and Maximum Storage EOR+. CO_2 supply prices should be sensitive to climate policy. *Ceteris paribus*, lower cost CO_2 should translate into higher utilisation rates and higher incremental recovery. There is a large technical potential for storage, and the potential for incremental production is equally large. Under all ETP scenarios by the IEA, the Net Present Value (NPV) of Advanced EOR+ comes out ahead. Current IEA CCS activities also include retrofitting CCS on coal-power in China and CCS in COP21.

13. Global CCS Institute Update

Victor Der provided an update on Global CCS Institute activities. The Institute will soon release "The Global Status of CCS: 2015," which is the Institute's annual publication on

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the progress of CCS globally. A summary report is currently available to CSLF participants, prior to the release of the official publication. The Institute will also host a series of events on CCS during COP21, and all participants are invited to attend. The Institute's objectives include:

- Accelerate global adoption of safe, commercially and environmentally sustainable CCS – Advocacy and Knowledge-Sharing
- Drive cooperation to deliver on "20 by 2020" diverse portfolio of fully-integrated, large-scale operating demos
- Coordinate efforts with networks of existing bodies to overcome barriers to broad industrial-scale deployment
- Focus on projects and support large-scale demos through facilitation of issues, discussion with key stakeholders (including governments) and networks for technical knowhow
- Act as active clearinghouse and standard setter for CCS information, aimed at technology and processes deployment

The Institute has held a number of past events to promote CCS, along with a number of key upcoming Institute events, and ongoing key activities to advance CCS. The Institute has also disseminated a number of lessons learnt and case study reports, which are valuable to current and future projects, along with some new and updated Institute publications and reports. Going forward, the Institute will continue to promote the importance of CCS through a number of methods, while maintaining a focus on serving its members' (currently 83 and growing) needs and key issues and priorities by taking actions within the Institute's mission.

14. Stakeholder Recommendations to CSLF

Barry Worthington, Executive Director of the United States Energy Association, spoke on CSLF Stakeholder activities. Over the past two days, CSLF Stakeholders focused on finance, regulations, communications, CCS in developing countries, and new transient technologies. Several new concepts were introduced including private activity bonds as a novel financing tool for CCS development, along with a sharper focus on carbon markets, particularly after COP21. The potential was raised for carbon capture units to be small, modular, factory manufactured units to supplement the current efforts to gain scale-up. Stakeholders discussed barriers to CCS, and questioned if there were any unrecognized obstacles. The CSLF Stakeholders have prepared a set of 15 recommendations for the CSLF Ministers, which were reviewed in preparation for the next day's CSLF Ministerial Meeting.

15. 2015 CSLF Ministerial Meeting

Khalid Abuleif delivered an update on the logistical aspects for the next day's 2015 CSLF Ministerial Meeting. Ministers and Heads of Delegation are expected from over 25 countries, as a number of non-CSLF members will also be represented.

16. Review of Draft 2015 CSLF Ministerial Communiqué

Jarad Daniels led the discussion regarding the draft 2015 CSLF Ministerial Communiqué. Input from countries was solicited and included into an updated CSLF Ministerial Communiqué, which was agreed on by the CSLF Policy Group for discussion at the next day's 2015 CSLF Ministerial Meeting.

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17. Review of Policy Group Messages to Ministers

Christopher Smith provided a review of the Policy Group Messages to the Ministers, which included an overview of the Policy Group's key activities and achievements since the last CSLF Ministerial in 2013. This message would be presented to the Ministers the next day.

18. Election of Policy Group Chair

Jarad Daniels presided over the election. Prior to the meeting, the United States was nominated for Policy Group Chair by Canada, China, the European Commission, Italy, Norway, and Russia. By consensus, the United States was re-elected as Policy Group Chair, for a period lasting three years.

19. Update on Future CSLF Meetings

Jarad Daniels provided a short summary of upcoming CSLF meetings. Options are still being considered for the 2016 CSLF Mid-Year Meeting. Takashi Kawabata, Japan, conveyed the Japanese government's desire to host the 2016 CSLF Annual Meeting in October 2016 in Japan. The budget request in Japan is currently in progress, and a final decision will be made in January 2016. The meeting will likely include a site tour of the Tomakomai CCS Demonstration Project, which will begin injection in April 2016.

20. Open Discussion and New Business

As a last minute addition to the agenda, the Republic of Serbia presented an application for CSLF membership, signed by Serbia's Minister of Mining and Energy Aleksandar Antić. After a review of the application letter, the Policy Group voted to approve and welcome Serbia as a CSLF member.

21. Action Items and Next Steps

Jarad Daniels, Director, 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:

- Approve Romania and Serbia as the CSLF's 24th and 25th members
- Approve the following five nominated projects 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
- Reelect the United States as Policy Group Chair for a period lasting three years

Action items from the meeting are as follows:

Item	Lead	Action
1	CSLF Capacity Building Governing Council	Continue soliciting new CSLF Capacity Building Program project proposals while also targeting new CSLF members that could be eligible to receive funds

Item	Lead	Action
2	France	As part of the Financing for CCS Projects work, convene a meeting after COP21 to discuss opportunities for the CSLF to advance financing of CCS projects, considering new data and efforts announced at COP21
3	Canada and Norway	Continue as co-leads for the Supporting Development of 2nd and 3rd Generation CCS Technologies work to support and coordinate development of 2nd and 3rd generation CCS technologies
4	CSLF Secretariat	Improve the CSLF website functionality to support efforts such as Supporting Development of 2nd and 3rd Generation CCS Technologies
5	China and the United States	Continue to lead on the Global Collaboration on Large-Scale CCS Projects work, and engage large-scale projects to discuss opportunities to leverage large projects, in coordination with the CSLF Technical Group and the Global CCS Institute
5	Saudi Arabia, Global CCS Institute, IEA	As part of the Communications effort, continue to refine the communications strategy based on the core messages agreed to by Ministers in the Communiqué; Define key audiences and find appropriate mechanisms to convey key messages to each respective target audience
6	CSLF Secretariat	Work with CSLF members to find a host for the 2016 Mid-Year Meeting; Work with Japan to potentially host the 2016 Annual Meeting in Japan, to highlight the Tomakomai CCS Demonstration Project.

22. Closing Remarks / Adjourn

Christopher Smith delivered closing remarks. He expressed his optimism for the next day's CSLF Ministerial Meeting, where the CSLF will highlight it's accomplishments to the Ministers and agree on the Ministerial Communiqué. Mr. Smith thanked Saudi Arabia as hosts and all participants for their contributions, and adjourned the meeting.

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Carbon Sequestration Leadership Forum
www.cslforum.org

CSLF-T-2016-01
Revised Draft: 27 January 2016
Prepared by CSLF Secretariat

DRAFT

Minutes of the Technical Group Meeting

Riyadh, Saudi Arabia
Monday, 02 November 2015

LIST OF ATTENDEES

Chair	Trygve Riis (Norway)
Delegates	
Australia:	Andrew Barrett (*Acting Vice Chair*), Max Watson
Canada:	Eddy Chui (*Vice Chair*), Michael Monea
China:	Xian Zhang
European Commission:	Jeroen Schuppers
France:	Didier Bonijoly, David Savary, Bernard Frois
Italy:	Sergio Persoglia
Japan:	Ryozo Tanaka, Takeshi Kawabata
Korea:	Chang Keun Yi, Chong Kul Ryu
Norway:	William Christensen, Lars Ingolf Eide
Saudi Arabia:	Khalid Abuleif, Ali Al-Meshari
South Africa:	Tony Surridge (*Vice Chair*)
United Arab Emirates:	Arafat Saleh Al-Yafei
United Kingdom:	Philip Sharman, Brian Allison
United States:	Mark Ackiewicz, Stephanie Duran

Representatives of Allied Organizations

Global CCS Institute:	Andrew Purvis
IEAGHG:	Tim Dixon

CSLF Secretariat	Richard Lynch, Adam Wong, Jarad Daniels

Invited Speakers

Australia:	Max Watson, Program Manager – CO_2 Storage, CO2CRC
France:	Isabelle Czernichowski-Lauriol, CGS Europe Coordinator, BRGM
Germany:	Frank Ennenbach, Director – R&D and Technology Environmental Control Solutions, Alstom
Korea:	Chang Keun Yi, Director – Climate Change Research Division, Korea Institute of Energy Research (KIER)
Saudi Arabia:	Khalid Abuleif, Sustainability Advisor to the Minister, Ministry of Petroleum and Mineral Resources
	Ali Al-Meshari, Manager – EXPEC Advanced Research Center, Saudi Aramco

Saudi Arabia:	Tidjani Niass, Chief Technologist – Carbon Management Division, Saudi Aramco Atieh Abu Raqabah, General Manager – Corporate Sustainability, Saudi Arabia Basic Industries Corp. (SABIC)
United States:	Nigel Jenvey, Chairman, CO_2 Capture Project

Observers

Chinese Taipei:	Vincent S.N. Chen, Yi-Shun Chen, Shoung Ouyang
Czech Republic:	Pavel Kavina
Germany:	Gianluca Di Federico
Korea:	Sangjoo Baek, Byeong Yeol Jeon
Mexico:	Rubén Beltrán-Palafox
Netherlands:	Maurice Hanegraaf, Gerrit van Tongeren
Norway:	Åse Slagtern
Qatar:	Saif Saeed Al-Naimi
Romania:	Mircea Toader
Saudi Arabia:	Saeed Al Alloush, Alla Yousef Al-Amrey, Saleh Al-Ansari, Abdullah Al-Ghabi, Abdelrahman Al-Gwaiz, Mohammed Al-Hamed, Waleed Al-Harbi, Awwad Al-Harthi, Abdullah Al-Hemdi, Adel Al-Khalifah, Sulaiman Al-Mayman, Saeed Al-Mehairbi, Abdullah Al-Musa, Hussain Al-Musawa, Ammar Al-Nahwi, Fouad Al Saeedi, Haitham Al-Soudani, Abdulrahman Al-Suhaibani, Abdullah Bogari, Muayad Matar, Hatem Mohiey, Wolfgang Heidug, Renato Hoogeveen, Medhat Nemitellah, Abdullah Tawlah, Muhammad Zahid
Turkey:	M.E. Burpinar, Nuri Kunt
United Arab Emirates:	Mohammed Al-Hamed, Hussain Al-Musawa, Khaled Al-Yagoubi
United States:	Ed Dodge, Scott McDonald, Tip Meckel, Shishir Tamotia
GCCSI:	Victor Der

1. Chairman's Welcome and Opening Remarks

The Chairman of the Technical Group, Trygve Riis, called the meeting to order and welcomed the delegates and observers to Riyadh. Mr. Riis mentioning that this is an important meeting because there will be decisions on future Technical Group activities. A working group led by the United States has developed a prioritized list of proposed new activities.

Mr. Riis also mentioned that the current meeting is, as usual, very content-rich, with many presentations of interest to attendees. This includes presentations from five projects which have been nominated for CSLF recognition. Mr. Riis closed his remarks by mentioning that he will make a presentation during the Ministerial Conference later in the week that will provide key messages and recommendations from the Technical Group.

2. Meeting Host's Welcome

Khalid Abuleif, Sustainability Advisor to Saudi Arabia's Minister of Petroleum and Mineral Resources, welcomed the meeting attendees to Riyadh. Mr. Abuleif stated that the 6^{th} CSLF Ministerial was a very significant event for Saudi Arabia, as it is the largest and highest profile meeting ever in this part of the world about carbon capture and storage (CCS) and would be a prolog to the Conference of Parties (COP) climate talks in Paris.

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3. Introduction of Delegates

Technical Group delegates present for the meeting introduced themselves. Fourteen of the twenty-three CSLF Members were represented. Observers from thirteen countries were also present.

4. Adoption of Agenda

The Agenda was adopted with the addition of a presentation by the Dry Solid Sorbent CO_2 Capture Project, which was nominated by Korea for CSLF recognition. This project had been a late addition to the previous day's PIRT meeting where it had been considered and sent forward to the Technical Group with a recommendation for its review and endorsement.

5. Approval of Minutes from Regina Meeting

The Minutes from the June 2015 Technical Group Meeting 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 June 2015 meeting in Canada and some of the highlights from that meeting. This was a five-day event, including a site visit to SaskPower's Boundary Dam CCS Project and CO_2 Capture Test Facility.

Mr. Lynch stated that there were seven Action Items from the June 2015 meeting, six of which are now complete. Still in progress is an activity assigned to the Secretariat to create a new section of the CSLF website for tracking progress on 2nd and 3rd generation CO_2 capture technologies. In addition to these Action Items, consensus was reached by the Technical Group on the following items:

- The Jingbian CCS Project is recommended by the Technical Group to the Policy Group for CSLF recognition. (*note: The project received CSLF recognition at the Policy Group's meeting two days later*.)
- The Technical Group will form a working group to develop additional Action Plan activities.
- The Technical Group will revise the CSLF Technology Roadmap (TRM) Interim Report, incorporating new information about the current status of technology for the identified ten technology needs areas.

Mr. Lynch also stated that four documents had been prepared as deliverables by the Technical Group for the Ministerial Conference, all of which are included in a special briefing book for the Ministers:

- TRM Interim Report (the Executive Summary from the full report, which reviews progress toward implementation for ten technology areas identified by the 2013 TRM);
- Report on Development of 2nd and 3rd Generation CO_2 Capture Technologies (the Executive Summary from the full report);
- Key Messages from the CSLF "Lessons Learned from Large-Scale CCS" Workshop (which was held as part of the Regina meeting); and

- Messages and Recommendations from the CSLF Technical Group (including takeaways from task forces and other Technical Group activities).

Mr. Lynch ended his presentation by noting that Mr. Riis is departing the CSLF after a very successful seven years as Technical Group Chairman. Mr. Lynch stated that it had been an a privilege to have worked alongside Mr. Riis as Secretariat and, in honor of the occasion, presented Mr. Riis with a CSLF Recognition Award. The meeting attendees added their best wishes with a round of applause.

7. Overview of CCS Activities in Saudi Arabia

Ali Al-Meshari, Manager of Saudi Aramco's EXPEC Advanced Research Center and Carbon Management Overall Coordinator for Saudi Arabia, gave a detailed presentation that described ongoing CCS activities in Saudi Arabia. The overall message was that technology development and deployment is a viable option to address climate change.

Dr. Al-Meshari stated that Saudi Arabia's program for CCS includes small-scale R&D being done at research centers and universities, where topics include CO_2 utilization, enhanced oil recovery (CO_2-EOR), CO_2 storage, CO_2 capture, and advanced materials. Larger-scale activities, sponsored by Saudi Aramco and SABIC, range from pilots and prototypes all the way up to large scale demonstrations. Five main areas of interest are CO_2-EOR, CO_2 sequestration, CO_2 capture from fixed sources (including oxy-fuel combustion), CO_2 capture from mobile sources (being demonstrated by two prototype vehicles), and industrial applications.

Dr. Al-Meshari closed his presentation by stating that Saudi Arabia already has a CSLF-recognized project (the Uthmaniyah EOR Project) and two others (a large oxy-fuel pilot project and a large-scale CO_2 utilization project) have been nominated for CSLF recognition at the current meeting. These prototype projects are important components in Saudi Arabia's overall carbon management plan.

8. Update on the CO_2 GeoNet and CGS Europe Projects

Isabelle Czernichowski-Lauriol, former CO_2 GeoNet President and current CGS Europe Coordinator, gave a presentation that described both of these CSLF-recognized projects. CO_2 GeoNet was initiated in 2004 as a Network of Excellence under the European Union's Sixth Framework Programme for Research and Technological Development (FP6). Founding members included 13 research institutes located in seven European countries. In 2008, CO_2 GeoNet transformed from being a project into being an Association (under French law) and as an independent and multidisciplinary organization, it has taken on a key role in building trust on CO_2 geological storage and supporting wide-scale CCS implementation. The CO_2 GeoNet Association is now the European scientific authority dealing with all aspects of geological storage of CO_2 and its activities have included joint research, scientific advice, training, and information / communication.

Concerning the CGS Europe Project, Dr. Czernichowski-Lauriol stated that the objectives of the project were to build a credible, independent and representative pan-European scientific body of expertise on CO_2 storage. To that end, the project has attracted a total of 24 partners representing 34 research institutes in 28 countries. The project ended in 2013, and in its three-year duration it has created and provided an information pathway which will help lead toward future large-scale implementation of CO_2 geological storage in Europe. Dr. Czernichowski-Lauriol closed her presentation by mentioning that since the end of the CGS Europe Project, many of its partners have continued to collaborate by joining the CO_2 GeoNet Association, and as a result, CO_2 GeoNet is now a reference source for stakeholders throughout the world.

9. Overview of Alstom's Oxyfuel Development Program

Frank Ennenbach, Director of R&D and Technology in Alstom Power's Environmental Control Solutions division, gave an overview presentation about Alstom's oxy-combustion technology activities. Alstom views oxy-combustion as a robust and flexible technology that works with all types of boilers and fuels. It can be used for large commercial units up to about 1,000 MW_e, including those with ultra-supercritical steam cycles. Oxy-combustion is cost competitive with other CO_2 capture technologies and has the advantage of not introducing new chemicals (such as amine sorbents) into a power plant.

Mr. Ennenbach stated that Alstom has been developing oxy-combustion technology since the 1990s, and has operated a 15 MW_{th} pilot plant in the United States. The technology is now ready for commercial-scale demonstration, which is anticipated at the United Kingdom's White Rose Project where a new 448 MW_e facility, currently in design, would treat 100% of the flue gas and have a 90% CO_2 capture rate. The CO_2 would be transported by pipeline to an offshore deep saline formation storage site.

Mr. Ennenbach also stated that Alstom and Saudi Aramco are collaborating on a large-scale pilot for testing oxy-combustion with heavy residue oil. Development has included a feasibility study for scale-up to commercial scale and also a three-week combustion test of the use of heavy residue fuel at Alstom's pilot plant in the United States. The large-scale pilot has been nominated for CSLF recognition, with a separate presentation on it later in the meeting.

10. 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.

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". This benchmarking study will actually be a workshop with a resulting report, the workshop taking place in the early part of 2016.

Mr. Dixon closed his presentation by mentioning that a special issue of the *International Journal of Greenhouse Gas Control* has been published in association with the IEAGHG, and contains 17 technical papers on CCS. One of them, "Review of CO_2 Storage Efficiency in Deep Saline Aquifers" by Stefan Bachu, is actually the final report of the Technical Group Task Force on Review of CO_2 Storage Efficiency in Deep Saline Aquifers. Mr. Dixon was requested to determine a way to allow access to journal paper that is the task force's final report via the CSLF website.

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

The Acting PIRT Chair, Andrew Barrett, gave a short presentation that summarized the previous day's meeting. Mr. Barrett stated that the PIRT had evaluated five projects which had been nominated for CSLF recognition and had recommended all five for consideration by the Technical Group:

- 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

Mr. Barrett also briefly summarized other outcomes from the PIRT meeting. Concerning future technology workshops, there was support for a workshop themed on lessons learned from completed CSLF-recognized projects. Concerning whether there should be a TRM update for 2016, three main possibilities were considered: a full re-write of the 2013 TRM, another TRM Interim Report of some kind, or doing nothing. The preferred option was not to do either a new TRM or an Interim Report, and instead use next year to formulate a process and structure for future TRM update activities. After ensuing discussion, there was agreement by the Technical Group for this approach and a new working group was formed to determine the future of the TRM process. The working group will be chaired by Australia, and will also include representation by Norway, South Africa, the United Kingdom, the United States, the IEAGHG, and the CSLF Secretariat. The working group was asked to present its recommendations at the next Technical Group meeting.

12. Review and Approval of Project Proposed for CSLF-Recognition: Dry Solid Sorbent CO_2 Capture Project
(*nominated by Korea and the United Kingdom*)

Chang Keun Yi, representing project sponsor KIER, gave a presentation about its CO_2 capture project. This is a pilot-scale project, located in southern Korea, which is demonstrating capture of CO_2 from a 10 MW_e 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 tonne 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 tonnes CO_2 per day at more than 95% CO_2 purity.

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

13. Review and Approval of Project Proposed for CSLF-Recognition: CO_2 Capture Project, Phase 4
(*nominated by the United Kingdom, Canada, and the United States*)

Nigel Jenvey, the Chairman of the CO_2 Capture Project, gave a presentation that described the 4^{th} phase of the project. This is a multi-discipline project whose 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.

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

14. Review and Approval of Project Proposed for CSLF-Recognition: CO2CRC Otway Project, Stage 2
(*nominated by Australia and the United States*)

Max Watson, representing project sponsor CO2CRC, presented the 2^{nd} stage of a multi-stage CO_2 storage program at the Otway Project, located in southwestern Victoria, Australia. The goal 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 modeling'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.

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

15. Review and Approval of Project Proposed for CSLF-Recognition: Oxy-Combustion of Heavy Liquid Fuels Project
(*nominated by Saudi Arabia and the United States*)

Tidjani Niass, representing project sponsor Saudi Aramco, gave a presentation about its oxy-combustion project. This is a large pilot project (approx. 30-60 MW_{th} 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 MW_{th} 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.

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

16. Review and Approval of Project Proposed for CSLF-Recognition: Carbon Capture and Utilization Project / CO_2 Network Project
(*nominated by Saudi Arabia and South Africa*)

Atieh Abu Raqabah, representing project sponsor SABIC, gave a presentation about its carbon capture and utilization project. 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.

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

17. Report from Task Force on Technical Barriers and R&D Opportunities for Offshore, Sub-Seabed Storage of CO_2

Task Force Chair Mark Ackiewicz gave a brief update on the task force and its final report. The task force was established at the March 2014 meeting with the mandate to identify technical barriers and R&D needs / opportunities for sub-seabed storage of CO_2. Mr. Ackiewicz stated that the task force had previously developed a draft of its final report for the June 2015 CSLF meeting in Regina. In all, the task force had 31 team members / contributors from seven countries and one multilateral organization, representing government agencies, universities, research laboratories, industry, and non-governmental organizations.

Mr. Ackiewicz provided information about the report's structure, which includes sections on all aspects of sub-seabed CO_2 storage such as resource assessments, CO_2 transport aspects, wellbore management, risk analysis, monitoring tools, and regulatory requirements. There are six main recommendations:

- Knowledge-sharing. Increase knowledge-sharing to define potential areas for international collaboration on offshore CO_2 storage. Need to leverage opportunities early and often.
- Storage Capacity Assessments. Much more information is needed in this area. Pre-qualify storage locations and basin evaluation. To facilitate doing this, make use of knowledge-sharing through international collaboration.
- Transport infrastructure. Offshore CO_2 transport is potentially expensive, but less subject to issues related to pipeline routing. Optimize current practices and infrastructure by taking advantage of pilot and demonstration projects.
- Offshore CO_2-EOR. Recent advances in subsea separation and processing could extend the current level of utilization of sea bottom equipment to also include the handling of CO_2 streams. Explore opportunities to leverage existing infrastructure and field tests, which could lead to a mechanism to catalyze and facilitate offshore storage opportunities and infrastructure.
- Understanding of CO_2 Impacts on the Subsea Environment. A significant body or research exists, but there are many challenges to efficient monitoring, particularly

to identify and correct non-natural change. Need to better understand buffering potential of sediments and the impact of longer-term exposures. More modeling is needed. Leverage existing work.

- Monitoring Technology Development. Technology exists, but there is room for improvement. The quantification of CO_2 within a reservoir still remains a challenge. Need better real-time data retrieval and navigation. Need further development in integrated in situ sensors.

Mr. Ackiewicz closed his presentation by mentioning some possible next steps. A task force on Offshore CO_2-EOR would be a good potential new activity area for the Technical Group. Also, the University of Texas Bureau of Economic Geology and the IEAGHG, both of which were task force members, have suggested that a workshop on offshore CO_2 storage would add to the overall knowledge base in this area. The final report from the Task Force will be made available at the CSLF website.

18. Decisions on Future Technical Group Action Plan Activities

Mark Ackiewicz, as lead of the working group to identify potential new Action Plan activities, gave a short presentation that described the working group's findings and recommendations. In all, fifteen possible areas of opportunity were investigated and opportunities considered to be of lesser priority were:

- Advanced Manufacturing Techniques Applied to CCS
- 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 Utilization Options
- Ship Transport of CO_2
- Definitions, TRL, scales
- Industrial CCS (revisit for application of 2nd generation technologies)
- Global Scaling of CCS
- Compact CCS
- Capturing CO_2 from Mobile Applications

Ensuing discussion resulted in the formation of three new task forces, in areas that received the highest priority:

- Offshore CO_2-EOR (to be chaired by Norway, with Canada, China, the United States, and the IEAGHG also as members)
- Bioenergy with CCS (to be chaired by the United States, with Italy, Norway, and the IEAGHG also as members)
- Improved Pore Space Utilisation (to be co-chaired by Australia and the United Kingdom, with France, Japan, the United Arab Emirates, and the IEAGHG also as members)

The suggested timelines for these new task forces are as follows: At the next Mid-Year Meeting (anticipated in June 2016), each task force should do a presentation on its overall plan and any activities. At the next Annual Meeting (anticipated in October 2016), each task force should have a written progress report or interim report of some kind. At the

2017 Mid-Year Meeting, each task force should have a draft of its final report, with a finished final report ready by the time of the 2017 Annual Meeting.

The Technical Group temporarily postponed a decision on forming a new task forces in one other high-priority area, Geo-steering / Pressure Management Techniques. There was also some interest in investigating the Industrial CCS area, but not enough yet to merit a new task force. These two areas will be taken up again at the next Technical Group meeting.

19. Update from Joint Task Force on the Development of 2nd and 3rd Generation CCS Technologies

Lars Ingolf Eide provided a status update on the Joint Policy Group-Technical Group Task Force on "Supporting Development of 2nd and 3rd Generation CCS Technologies". This task force has been established with Norway as the lead for the Technical Group and Canada the lead for the Policy Group. The technical mandate of the task force includes:

- Mapping/identifying 2nd and 3rd generation technologies under consideration in CSLF member countries, especially those that may mature in the 2020-2030 timeframe;
- Identifying major challenges facing development of these next generation technologies; and
- Using existing networks such as the International CCS Test Centre Network to map potential for testing these next generation technologies at existing test facilities.

Mr. Eide stated that a draft final report has been prepared which summarizes existing information in the area of 2nd and 3rd generation CO_2 capture technologies, and that the report has been organized to provide descriptions of the technologies and their development pathways as well as information on existing CCS test centers where some of these technologies could be scaled-up. Mr. Eide stated that the report does not address the economics for use of these technologies but does indicate technology readiness levels. Also, details concerning overall process development, integration, and materials development has been excluded.

Mr. Eide provided several recommendations for follow-up by the CSLF. These include finding ways to implement mechanisms that will allow technology developers and test facility operators to cooperate in mutually beneficial and cost-effective ways. Also, the CSLF could work to increase the opportunities for project developers to participate in extended visits to other demonstration projects and test centers, and the CSLF could work toward developing a consistent terminology for new CO_2 capture technologies, as both the technology maturity and scale of operation (i.e., pilot vs. demonstration) currently have imprecise boundaries.

At the conclusion of Mr. Eide's presentation, there was agreement that the Secretariat will circulate a copy of the final report to all Technical Group delegates, and that the delegates will provide any comments, additions and corrections regarding the test facilities section of the report to Mr. Eide. The Secretariat will make a finalized version of the report available at the CSLF website.

20. Update on International CO_2 Capture Test Centre Network

Lars Ingolf Eide gave a short presentation on the status of the International CO_2 Capture Test Centre Network (ITCN), which was officially launched in 2013 to accelerate CCS technology development. Mr. Eide stated that the network's main function is to facilitate knowledge sharing of operational experience and non-confidential information, and that analysis and problem solving (and *not* data collection) is the network's focus. Criteria for a test facility's membership in the network is that the facility must be operating on real flue gases (i.e., be connected to a power plant or industrial plant), it must have the intent of being neutral in any technology decisions, and it must be willing to share information and receive visitors.

Mr. Eide stated that the knowledge-sharing aspects of the ITCN has been manifested in three workshops, in Mongstad, Norway in May 2014 (which was focused on amine-based post-combustion capture), in Austin, Texas, USA, in October 2014 (which was an exchange of experiences on how best to measure and model amine emissions), and in Wilhelmshaven, Germany in April 2015 (which was focused on aerosols and mist formations). A report from the first workshop, on lessons learned from measurement of amine and amine degradation products, is in preparation.

Mr. Eide stated that ITCN activities in 2016 will be aimed at increasing insight and awareness of different technologies for relevant stakeholders in order to reduce risks and increase investments in CCS technology. The ITCN may also broaden its membership base to include universities and small test centers. It will also establish relationships with other test networks, as well as explore business focus areas for future collaborations.

21. Election of Technical Group Chair and Vice Chairs

Richard Lynch presided over this item of the agenda. Mr. Lynch stated that according to the CSLF Terms of Reference and Procedures, CSLF Chairs and Vice Chairs are elected every three years. The previous election for the Technical Group was in 2012 at the CSLF Annual Meeting in Perth, Australia.

By consensus, Norway was re-elected as Chair, and Australia, Canada, and South Africa were re-elected as Vice Chairs.

22. Update on Future CSLF Meetings

Richard Lynch provided a short summary of upcoming CSLF events. Concerning the 2016 CSLF meetings, Mr. Lynch stated that there was nothing yet to report concerning the mid-year meeting but Japan may be willing to host the year-end meeting. Takashi Kawabata was called on for additional comments and welcomed the opportunity to bring the CSLF to Japan in October 2016. Mr. Kawabata stated that a budgetary request for the meeting has been made, so Japan's hosting of the 2016 CSLF Annual Meeting should be considered tentative at this point with a final decision expected by the end of the year.

23. Open Discussion and New Business

No additional new activities were proposed. Tony Surridge read a short poem about climate change that he had written for the occasion.

24. Review of Consensuses Reached and Action Items

Consensus was reached on the following items:

- The Dry Solid Sorbent CO_2 Capture Project is recommended by the Technical Group to the Policy Group for CSLF recognition.

- The CO_2 Capture Project – Phase 4 is recommended by the Technical Group to the Policy Group for CSLF recognition.
- The CO2CRC Otway Project – Stage 2 is recommended by the Technical Group to the Policy Group for CSLF recognition.
- The Oxy-Combustion of Heavy Liquid Fuels Project is recommended by the Technical Group to the Policy Group for CSLF recognition.
- The Carbon Capture and Utilization Project / CO_2 Network Project is recommended by the Technical Group to the Policy Group for CSLF recognition.
- The Technical Group forms a working group to determine the way forward for future TRM update activities. Members of the working group are Australia (Chair), Norway, South Africa, the United Kingdom, the United States, the IEAGHG, and the CSLF Secretariat.
- The Technical Group forms a new Task Force on Offshore CO_2-EOR, to be chaired by Norway. Other members are Canada, China, the United States, and the IEAGHG.
- The Technical Group forms a new Task Force on Bioenergy with CCS, to be chaired by the United States. Other members are Italy, Norway, and the IEAGHG.
- The Technical Group forms a new Task Force on Improved Pore Space Utilisation, to be co-chaired by Australia and the United Kingdom. Other members are France, Japan, the United Arab Emirates, and the IEAGHG.
- The Technical Group is temporarily postponing decisions on forming new task forces in the areas of Geo-steering / Pressure Management Techniques and Industrial CCS. These will be taken up again at the next meeting.

Action items from the meeting are as follows:

Item	Lead	Action
1	Technical Group Chair	Provide the Technical Group's recommendation to the Policy Group that five new projects be recognized by the CSLF. (*Note: this was done at the November 3rd Policy Group meeting.*)
2	IEAGHG	Determine a way to allow access to journal paper that is the Task Force on Review of CO_2 Storage Efficiency in Deep Saline Aquifers final report via the CSLF website.
3	Working Group on TRM	Make recommendations on the future of the TRM process at the next Technical Group meeting.
4	Secretariat	Make final report from the Task Force on Technical Barriers and R&D Opportunities for Offshore, Sub-Seabed Storage of CO_2 available at CSLF website.
5a	Secretariat	Circulate a copy of the final report from the Task Force on Supporting Development of 2nd and 3rd Generation CCS Technologies to all Technical Group delegates.

Item	Lead	Action
5b	Delegates	Provide comments on the test facilities section of the task force report.
5c	Secretariat	Make a finalized version of the task force report available at the CSLF website.

25. Closing Remarks / Adjourn

In adjourning the meeting, Trygve Riis thanked the meeting hosts, especially Hamoud AlOtaibi who was the CSLF's main point of contact. Mr. Riis thanked the Secretariat for its support, thanked the delegates for their active participation, and introduced the new Technical Group Chair, Åse Slagtern. Mrs. Slagtern has many years of experience associated with CCS; she is currently involved with Norway's CLIMIT research program on CCS and is Vice Chair of the IEAGHG's Executive Committee. William Christensen, on behalf of Norway and the CSLF, thanked Mr. Riis for his seven years of strong leadership for the Technical Group and welcomed Mrs. Slagtern as the new Chair.

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Carbon Sequestration Leadership Forum
www.cslforum.org
CSLF-T-2016-03
26 May 2016

TECHNICAL GROUP

Technology Roadmap Update

Background

At the September 2015 CSLF Ministerial Meeting in Riyadh, the Technical Group appointed a new Working Group to formulate a process and structure of future update activities for the CSLF Technology Roadmap (TRM). This new Working Group, chaired by Australia, was asked to present its recommendations at the next Technical Group meeting. This progress report from the Working Group describes the methodology and plan for the next TRM update.

Action Requested

The Technical Group is requested to review the TRM Working Group's progress report.

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Carbon Sequestration Leadership Forum
www.cslforum.org
CSLF-T-2016-03
26 May 2016

CSLF Technology Roadmap Update – Progress Report

At the Riyadh CSLF Technical Group meeting it was agreed that a Working Group be tasked with the development of the next version of the Technical Roadmap to be completed by the 2017 Ministerial Conference.

Three options were canvassed:

- A full re-write of the 2013 Technical Roadmap
- A refresh of the 2013 Technical Roadmap
- Do nothing

The preferred option is the refresh, and it was agreed to use the next several months to formulate a process and structure for future TRM update activities.

The Working Group is chaired by Australia, and includes representation from Norway, South Africa, the United Kingdom, the United States, the IEAGHG, and the CSLF Secretariat. The working group was asked to present its recommendations at the next Technical Group meeting.

Progress to date

The Working Group has met three times via teleconference (1 March and 12 April) and identified the main areas of the current TRM that need updating and the agreed approach is to focus on updating Section 4 in 2016.

It was noted that the refreshed version will need to incorporate the outcomes of COP21. Time horizons will remain as 2020, 2030 and 2050.

The members of the Working Group have been assigned components of Section 4 to update as follows:

- 4.1 – Capture – Norway
- 4.2 – Transport – yet to be assigned
- 4.3 – Storage – Australia with IEAGHG working on 4.3.2 (Monitoring and Mitigation)
- 4.4 – Infrastructure – yet to be assigned
- 4.5 – Utilization – United States

A forward plan for the overall update process will be presented at the 2016 CSLF Mid-Year Meeting.

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Carbon Sequestration Leadership Forum
www.cslforum.org
CSLF-T-2016-04
01 April 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. All other recommended actions have not yet received enough interest to form new task forces.

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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Carbon Sequestration Leadership Forum
www.cslforum.org
CSLF-T-2016-04
01 April 2016

CSLF Technical Group Action Plan Status

(as of April 2016)

Current Actions

- Offshore CO_2-EOR (*Task Force chair: Norway*)
- Improved Pore Space Utilization (*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
- Industrial CCS
- 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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MEETING SUMMARY
Projects Interaction and Review Team (PIRT) Meeting
Riyadh, Saudi Arabia
01 November 2015

Prepared by the CSLF Secretariat

LIST OF ATTENDEES

PIRT Active Members

Australia:	Andrew Barrett (Acting Chair), Max Watson
Canada:	Eddy Chui, Mike Monea
China:	Xian Zhang
European Commission:	Jeroen Schuppers
France:	Didier Bonijoly, David Savary
Japan:	Ryozo Tanaka
Norway:	Trygve Riis
Saudi Arabia:	Hamoud Al-Otaibi
South Africa:	Tony Surridge
United Kingdom:	Brian Allison, Philip Sharman
United States:	Mark Ackiewicz
GCCSI:	Victor Der
IEAGHG:	Tim Dixon

Other CSLF Delegates

Australia:	Josh Cosgrave
France:	Bernard Frois
Korea:	Chong Kul Ryu, Chang Keun Yi

CSLF Secretariat Richard Lynch, Adam Wong

Invited Speakers

Australia:	Max Watson, Program Manager – CO_2 Storage, CO2CRC
Korea:	Chang Keun Yi, Director – Climate Change Research Division, Korea Institute of Energy Research (KIER)
Saudi Arabia:	Tidjani Niass, Chief Technologist – Carbon Management Division, Saudi Aramco
	Atieh Abu Raqabah, General Manager – Corporate Sustainability, Saudi Arabia Basic Industries Corp. (SABIC)
United States:	Nigel Jenvey, Chairman, CO_2 Capture Project

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Observers

Chinese Taipei:	Vincent S.N. Chen, Yi-Shun Chen, Shoung Ouyang
Czech Republic:	Pavel Kavina
Norway:	Åse Slagtern
Romania:	Mircea Toader
Saudi Arabia:	Saeed Al-Alloush, Alla Yousef Al-Amrey, Saleh Al-Ansari, Aied Al-Dosari, Abdelrahman Al-Gwaiz, Fahad Al-Holi, Abdulaziz Al-Jodai, Adel Al-Khalifah, Fouad Al-Saeedi, Fahad Al-Rashidi, Abdulrahman Al-Suhaibani, Ijaz Chaudhary, Zafar Chaudhry, Abdullah Ghabi, Ahmad Hasanain, Renato Hoogeveen, Abdullah Maghrabi, Muayad Matar, Shashidhara Math, Pieter Smeets, Shishir Tamotia, Abdullah Tawlah
United States:	Ed Dodge, Tip Meckel, Michael Moore, Barry Worthington
IEA:	Tristan Stanley

1. Welcome and Review of PIRT Functions

Acting PIRT Chairman Andrew Barrett introduced himself and welcomed participants to the 24th meeting of the PIRT. Mr. Barrett informed the PIRT members that he was replacing Clinton Foster, who had retired. Mr. Barrett stated that the current meeting would include several presentations from projects being nominated for CSLF recognition, and also a discussion on future PIRT activities including options for the next iteration of the CSLF Technology Roadmap (TRM).

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 with the addition of a presentation by the "Dry Solid Sorbent CO_2 Capture Project", which had been nominated by Korea for CSLF recognition. This project had been proposed for CSLF recognition too near the PIRT meeting date for a normal review cycle, but PIRT Active Members agreed to allow the project to be reviewed at the current meeting.

4. Approval of Meeting Summary from Regina PIRT Meeting

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

5. Report from CSLF Secretariat

Richard Lynch provided a multi-part report from the Secretariat, which covered the status of CSLF-recognized projects, PIRT consensuses from the June 2015 meeting in Regina, and the TRM Interim Report.

Concerning the portfolio of CSLF-recognized projects, Mr. Lynch stated that as of the October 2015 there were 29 active projects and 15 completed projects, spread out over

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five continents. Recent changes include addition of the Jingbian Carbon Capture and Storage (CCS) Project, which was recognized by the CSLF at its June meeting in Regina, and successful completion of the CGS Europe Project, the CO2CRC Otway Project Stage 1, and the CO_2 Capture Project, Phase 3. For the current meeting, five new projects have been nominated for CSLF recognition.

Mr. Lynch reported that there were two consensuses from the Regina meeting. The PIRT recommended approval by the Technical Group of the Jingbian CCS Project, and the PIRT will decide at the Riyadh meeting the format and frequency of future TRM updates.

Concerning the draft TRM Interim Report, Mr. Lynch stated that this document is an outgrowth of the 2013 TRM which had been launched at the 5th CSLF Ministerial in 2013. An objective of the 2013 TRM was to answer three key questions:

- What is the current state of CCS technology and deployment, particularly in CSLF member countries?
- Where should CCS be by the year 2020 and beyond?
- What is needed to get to these advanced stages of development and deployment, while also addressing the different circumstances of developed and developing countries?

The 2013 TRM identified ten technology needs areas, and to gauge progress a template for gathering information about these ten areas was sent to representatives of many different research organizations which are working on carbon capture, utilization and storage (CCUS). Information gleaned from completed templates was used to prepare the initial draft of the TRM Interim Report, which was reviewed by the PIRT at its Regina meeting. It was decided that the initial draft inexactly described progress in the ten technology needs areas, so a second survey was done to obtain viewpoints from world-class experts on technology readiness in the technology needs areas. The Secretariat then edited the new information into the final version of the report, which became a deliverable to the CSLF Ministers.

Mr. Lynch provided the following conclusions and recommendations from the TRM Interim Report:

- Except for a very few niche industrial sector applications, for 1st generation technologies, none of the ten technology needs areas perceived as progress being ‘fast moving’. Instead, ‘slow to moderate’ progress toward implementation was generally perceived, mainly because of existing policy and economic barriers.
- Technical readiness of first generation CCUS technologies were perceived, in general, as ready for large-scale commercial deployment.
- Concerning economic barriers, governments should urgently consider methods to assist stakeholders to significantly drive down the cost of CCUS deployment, since it is the stakeholders who will be making the majority of the financial investments.
- Concerning policy barriers, governments should review institutional regulatory policies to identify how these barriers to CCUS deployment may be reduced.
- Concerning technology barriers, stakeholders should increase their mechanisms for sharing best practices, particularly regarding communications, regulation and cost reduction, and pledge to engage in public-private partnerships to encourage

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the development of additional demonstration projects and facilitate the development of CCUS projects internationally.

Mr. Lynch closed his presentation with the following messages to Ministers that were included in the report:

- Ministers should be champions of CCS. CCS should be a key component of any CO_2 emissions reduction strategy.
- Ministers should recognize the contribution that CCS can provide in terms of energy security.
- Ministers should understand that CCS deployment will create and preserve jobs.

6. Review and Approval of Project Proposed for CSLF-Recognition: CO_2 Capture Project, Phase 4

Nigel Jenvey, the Chairman of the CO_2 Capture Project, gave a presentation that described the 4th phase of the project. This is a multi-discipline project whose 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.

Outcome: After a comprehensive discussion, there was unanimous consensus by the PIRT to recommend approval of the CO_2 Capture Project, Phase 4 by the Technical Group.

7. Review and Approval of Project Proposed for CSLF-Recognition: CO2CRC Otway Project, Stage 2

Max Watson, representing project sponsor CO2CRC, presented the 2nd stage of a multi-stage CO_2 storage program at the Otway Project, located in southwestern Victoria, Australia. The goal 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.

Outcome: After a comprehensive discussion, there was unanimous consensus by the PIRT to recommend approval of the CO2CRC Otway Project, Stage 2 by the Technical Group.

8. Review and Approval of Project Proposed for CSLF-Recognition: Oxy-Combustion of Heavy Liquid Fuels Project

Tidjani Niass, representing project sponsor Saudi Aramco, gave a presentation about its oxy-combustion project. This is a large pilot project (approx. 30-60 MW_{th} 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 MW_{th} 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.

Outcome: After a comprehensive discussion, there was unanimous consensus by the PIRT to recommend approval of the Oxy-Combustion of Heavy Liquid Fuels Project by the Technical Group.

9. Review and Approval of Project Proposed for CSLF-Recognition: Carbon Capture and Utilization Project / CO_2 Network Project

Atieh Abu Raqabah, representing project sponsor SABIC, gave a presentation about its carbon capture and utilization project. 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.

Outcome: After a comprehensive discussion, there was unanimous consensus by the PIRT to recommend approval of the Carbon Capture and Utilization Project / CO_2 Network Project by the Technical Group.

10. Review and Approval of Project Proposed for CSLF-Recognition: Dry Solid Sorbent CO_2 Capture Project

Chang Keun Yi, representing project sponsor KIER, gave a presentation about its CO_2 capture project. This is a pilot-scale project, located in southern Korea, which is demonstrating capture of CO_2 from a 10 MW_e 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 tonne 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 tonnes CO_2 per day at more than 95% CO_2 purity.

Outcome: After a comprehensive discussion, there was unanimous consensus by the PIRT to recommend approval of the Dry Solid Sorbent CO_2 Capture Project by the Technical Group.

11. Future PIRT Activities

Mr. Barrett stated that future PIRT activities mostly fall into three main categories: review of projects proposed for CSLF recognition, planning for future technology workshops, and updating the TRM. Concerning future workshops, Ryozo Tanaka noted that Japan is planning to host the 2016 Annual Meeting, including a workshop, and expressed his thought that at least part of the workshop should highlight Japan's CCS activities and include presentations by several Japanese speakers. Mark Ackiewicz proposed that it would be useful for a workshop to take a retrospective look at completed projects, with a focus on challenges and lessons learned. And Tim Dixon recommended that knowledge sharing be a central theme for all future workshops.

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Concerning future updates to the TRM, Mr. Lynch stated that there were three main options for 2016: do a complete revision of the 2013 TRM, do another Interim Report, or do nothing. Philip Sharman suggested that there probably was not a near-term need for either an overall revision or a new Interim Report, as the current Interim Report shows that the 2013 TRM is still a good document that has not significantly aged. Trygve Riis agreed, but stated that the PIRT should not wait until the end of 2016 to decide on what comes next. Mr. Riis suggested that, during 2016, the PIRT determine a template for a 2017 TRM in terms of format and desired content. After further brief discussion there was general agreement on this approach. To that end, Mr. Barrett stated that the PIRT will recommend that the Technical Group assign a working group that will formulate process and structure for future TRM activities.

12. Open Discussion and New Business

Mr. Lynch noted that the name of this task force includes the words 'projects interaction' and inquired if more should be done to better engage the sponsors of projects in the CSLF portfolio. Mr. Sharman responded that the PIRT is already actively engaged through workshops and from soliciting their input to the TRM. Mr. Ackiewicz agreed, but suggested that the PIRT could still use a more proactive approach starting with determining what specific information it needs from project sponsors. No action was proposed, though this may be taken up again at a future PIRT meeting.

13. Adjourn

Mr. Barrett thanked the attendees for their participation, expressed his appreciation to Saudi Arabia for hosting the 6th CSLF Ministerial, and adjourned the meeting.

Summary of Consensuses

- The PIRT recommends approval by the Technical Group for the CO_2 Capture Project – Phase 3.
- The PIRT recommends approval by the Technical Group for the CO2CRC Otway Project Stage 2.
- The PIRT recommends approval by the Technical Group for the Oxy-Combustion of Heavy Liquid Fuels Project.
- The PIRT recommends approval by the Technical Group for the Carbon Capture and Utilization Project / CO_2 Network Project.
- The PIRT recommends approval by the Technical Group for the Dry Solid Sorbent CO_2 Capture Project.
- The PIRT recommends that the Technical Group assign a working group to formulate process and structure for future revisions of the TRM.

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Revised: November 2013

Terms of Reference

CSLF Projects Interaction and Review Team

Background

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

PIRT Functions

The PIRT has the following functions:

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

Membership of the PIRT

The PIRT consists of:

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

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

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

Projects for CSLF Recognition

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

Operation and Procedures of the PIRT

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

Project Recognition

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

Information Update and Workshops

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

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Carbon Sequestration Leadership Forum

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.

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7. Commencement, Modification, Withdrawal, and Discontinuation

7.1 Commencement and Modification

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

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

7.2 Withdrawal and Discontinuation

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

8. Counterparts

This Charter may be signed in counterpart.

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CARBON SEQUESTRATION LEADERSHIP FORUM
TERMS OF REFERENCE AND PROCEDURES

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

1. Organizational Responsibilities

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

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

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

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

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

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

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

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

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

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

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

2. Additions to Membership

2.1. Application.

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

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

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

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

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

3. CSLF Governance

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

3.2. Meetings.

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

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

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

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

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

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

3.3. Organization of the Policy and Technical Groups

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

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

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

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

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

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

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

4. CSLF Projects

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

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

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

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

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

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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

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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

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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

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

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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

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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

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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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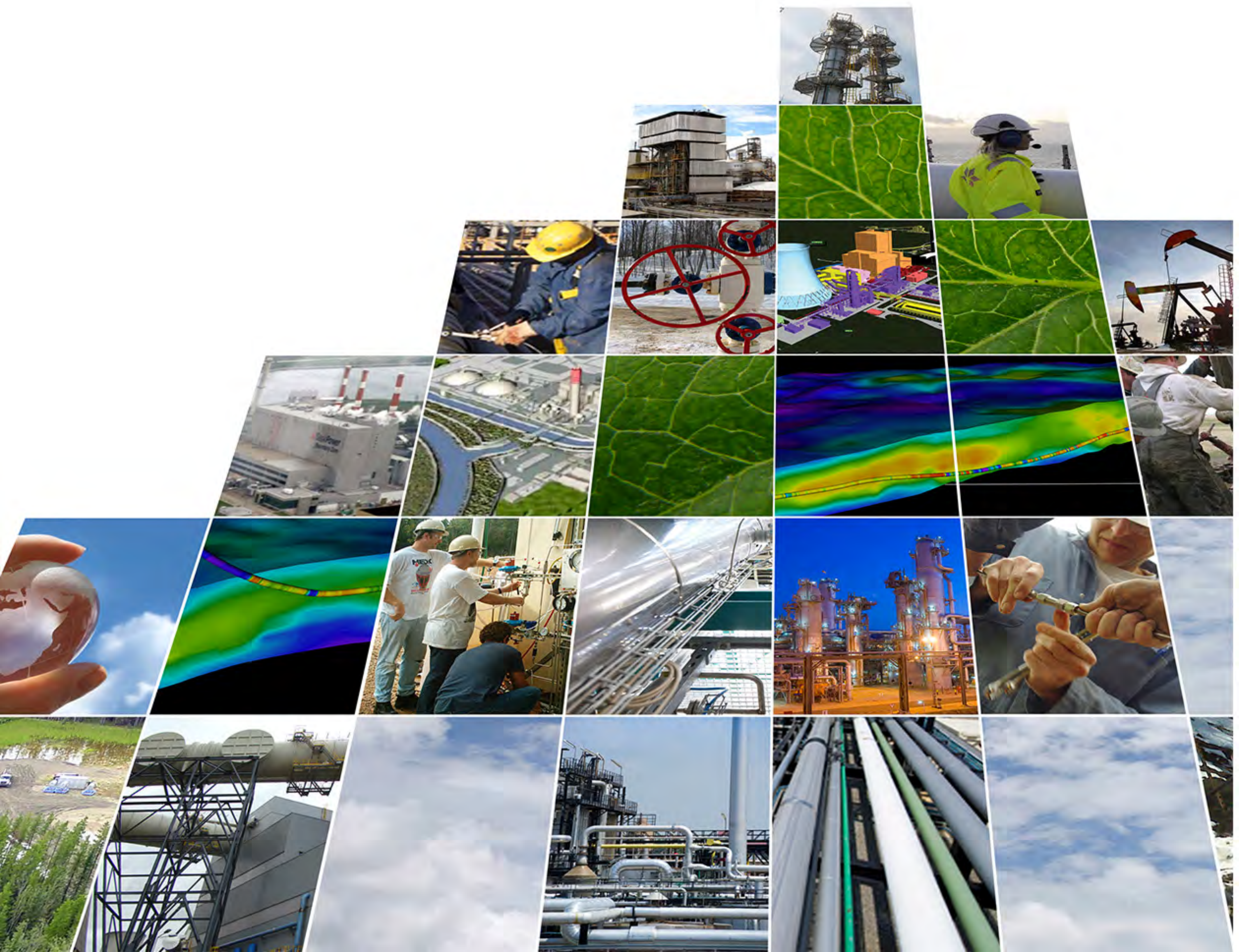
carbon sequestration leadership forum

2013

Carbon Sequestration

TECHNOLOGY ROADMAP



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.

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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^oC 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

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

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

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

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

4. Identified Technology Needs

4.1. Capture

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

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

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

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

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

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

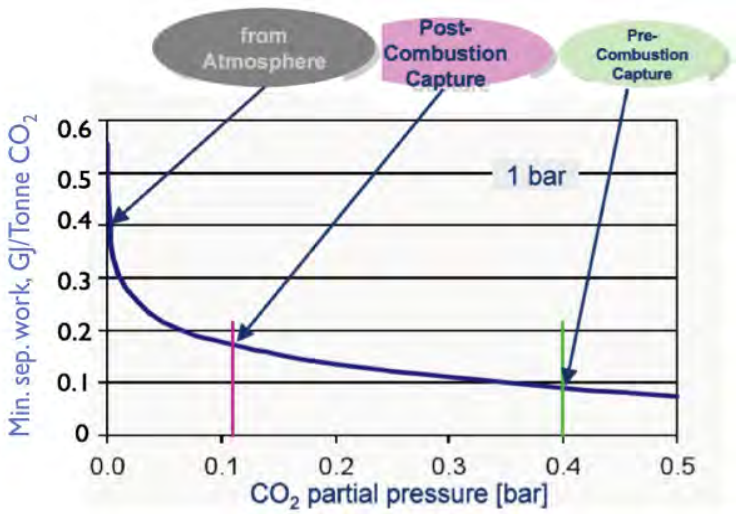

Figure 1: Theoretical minimum separation work of CO_2 from a flue gas depending on the partial pressure of CO_2 [modified from Bolland et al., 2006]

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

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

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

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

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

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

4.1.1. Recommendation 1: CO_2 Capture Technologies in Power Generation

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

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

Towards 2030:

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

Towards 2050:

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

4.1.2. Recommendation 2: CO_2 Capture in the Industrial Sector

Towards 2020:

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

Towards 2030:

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

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

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

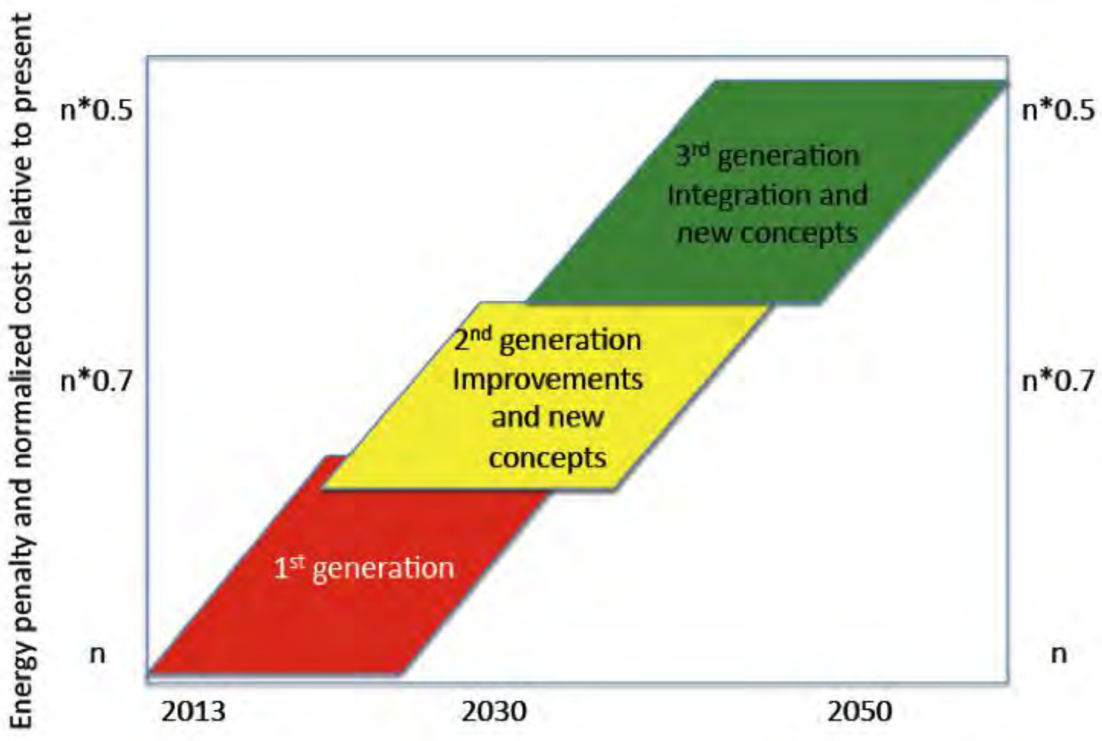

Figure 2: Priorities for CCS technology development. The energy penalty and normalized costs are shown in relation to the present level (n), i.e. equivalent to reduction by 30% in 2030 and 50% towards 2050.

4.2. Transport

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

4.2.1. Recommendation 3: CO_2 Transport

Towards 2020:

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

4.3. Storage

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

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

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

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

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

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

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

Other issues that need RD&D are:

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

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

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

4.3.1. Recommendation 4: Large-Scale CO_2 Storage

Towards 2020:

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

Towards 2030:

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

Towards 2050:

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

4.3.2. Recommendation 5: Monitoring and Mitigation/Remediation

Towards 2020:

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

Towards 2030:

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

4.3.3 Recommendation 6: Understanding the Storage Reservoirs

Towards 2020:

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

4.4. Infrastructure and the Integrated CCS Chain

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

Other RD&D needs include:

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

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

4.4.1. Recommendation 7: Infrastructure

Towards 2020:

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

Towards 2030:

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

4.5. Utilization

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

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

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

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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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