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# 2012 CSLF ANNUAL MEETING

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Perth, Australia  
October 24–26, 2012



## **2012 CSLF ANNUAL MEETING DOCUMENTS BOOK**

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# Carbon Sequestration Leadership Forum

[www.cslforum.org](http://www.cslforum.org)



September 4, 2012

Dear Colleague:

The Carbon Sequestration Leadership Forum (CSLF) is now planning its next annual meeting to be held in Perth, Australia, on October 24 - 26, 2012. I would like to thank Australia, which hosted the second CSLF Ministerial in 2004, for its generous hospitality in again hosting a major CSLF meeting.

At last year's Ministerial in Beijing, the CSLF Charter was renewed and the mandate of the CSLF was expanded from Carbon Capture and Storage (CCS) to Carbon Capture Utilization and Storage (CCUS). The importance of the CSLF was clearly recognized by our Ministers. Under that new Charter and its broadened mandate, we began to collaborate on our new CSLF Strategic Plan. These are all important steps but, as we all know, much more needs to be done to make CCUS a reality.

The value of collaboration through the CSLF is greater today than at any other time in its history. The need for CCUS has increased over that time, but so have the challenges to its development and commercial deployment. Global carbon dioxide emissions continue to increase and much of that increase is from facilities that would benefit from CCUS. The International Energy Agency has gone from projecting a 2-degree Celsius increase in global temperatures as a worst case scenario to projections of 4 and even 6 degrees Celsius increases. Many integrated, commercial-scale CCUS projects are now ready to be built. But these projects face the challenges of the high costs of first plants. Many projects have been cancelled due to their inability to obtain financing, much of the public still lacks an understanding of CCUS, and legal and regulatory frameworks remain not fully developed. These are challenges that we have long discussed, but global economic uncertainty and tight government budgets make these business challenges even more difficult.

We all share a common commitment to advancing CCUS as a vital and necessary means of mitigating climate change. Yet, we face the realities of today's challenges and must act on that commitment. Collaboration through the CSLF will make our actions more effective and timely.

The 2012 CSLF meeting must focus on meeting these critical challenges, and the Policy Group and Technical Group have much to discuss. The Policy Group will address how international collaboration should be used to advance demonstration projects and develop a strategy for next year's Ministerial. The Policy Group will also elect a Chair. The Technical Group will develop a plan for launching its 2013 Roadmap and will also elect a Chair, as well as three Vice Chairs. Our agenda is very wide ranging and promises to be productive.

I look forward to working with you and seeing you in Perth.

Sincerely,

Charles D. McConnell  
Chairman  
CSLF Policy Group



## CSLF IS GOING GREEN\*

### 2012 CSLF Annual Meeting

Perth, Australia

24-26 October 2012

### Block Agenda

	Wednesday 24 October	Thursday 25 October	Friday 26 October
Morning	<p><b>CSLF Secretariat Office</b> <i>Studio Room</i> <i>8:00am open</i></p> <p><b>Meeting Registration</b> <i>Botanicals Foyer</i> <i>08:00-11:00</i></p> <p><b>CSLF Task Force Meetings</b> (Policy Group) <i>Botanical #4</i> <i>11:00-12:00</i></p> <p><b>Half-day Site Visit</b> <i>Australian Resources Research Centre (ARRC) and Alcoa's carbon capture plant in Kwinana</i> <i>08:30-12:30</i></p>	<p><b>CSLF Secretariat Office</b> <i>Studio Room</i> <i>7:30am open</i></p> <p><b>Meeting Registration</b> <i>Astral Foyer</i> <i>07:30-12:00</i></p> <p><b>CSLF Policy Group Meeting</b> <i>Astral 1 &amp; 2</i> <i>08:30-12:30</i></p> <p><b>CSLF Technical Group Meeting</b> <i>Astral 3</i> <i>09:00-12:30</i></p>	<p><b>Joint Meeting of CSLF Policy and Technical Groups</b> <i>Astral 1 &amp; 2</i> <i>08:30-13:30</i></p>
		<p><b>Lunch</b> <i>Astral Foyer</i> <i>12:30-13:30</i> (hosted by Global CCS Institute)</p>	<p><b>Lunch</b> <i>Astral Foyer</i> <i>13:30-14:30</i> (hosted by Global CCS Institute)</p>
Afternoon	<p><b>Meeting Registration</b> <i>Botanicals Foyer</i> <i>12:00-14:00</i></p> <p><b>CSLF Task Force Meetings</b> (Technical Group) <i>Botanical #3</i> <i>15:00-18:30</i></p> <p><b>CSLF Task Force Meetings</b> (Policy Group) <i>Botanical #4</i> <i>14:00-16:30</i></p> <p><b>CSLF Stakeholders Meeting</b> <i>Botanical #4</i> <i>16:30-17:30</i></p> <p><b>Half-day Site Visit</b> <i>Australian Resources Research Centre (ARRC) and Alcoa's carbon capture plant in Kwinana</i> <i>13:00-16:30</i></p>	<p><b>CSLF Policy Group Meeting</b> <i>Astral 1 &amp; 2</i> <i>13:30-17:30</i></p> <p><b>CSLF Technical Group Meeting</b> <i>Astral 3</i> <i>13:30-16:30</i></p>	
Evening	<p><b>Welcome Reception</b> <i>Astral Foyer</i> <i>18:30-20:00</i> (hosted by the Chevron-operated Gorgon Project)</p>	<p><b>Reception / Dinner</b> <i>Matilda Bay Restaurant</i> <i>19:00-21:00</i> (hosted by West Australian Department of Mines and Petroleum)</p>	

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.



## CSLF IS GOING GREEN\*

### CSLF TASK FORCE MEETING SCHEDULE

Wednesday, October 24, 2012

8:00-10:00am 12:00-2:00pm	<b>REGISTRATION</b> <i>Botanicals Foyer</i>
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Room	Botanical #3	Botanical #4
8:00-10:00am		
10:00-11:00am		
11:00am-Noon		Capacity Building Governing Council
Noon-1:00pm		
1:00-2:00pm		
2:00-3:00pm		Risk and Liability Task Force
3:00-4:00pm	CO <sub>2</sub> Utilization Task Force	Financing CCS Task Force ( <i>ends at 4:30pm</i> )
4:00-5:00pm	Technology Gaps Closure Task Force	
5:00-6:30pm	Projects Interaction and Review Team (PIRT)	Stakeholders Meeting ( <i>starts at 4:30pm</i> )

7:45am-5:30pm	<b>CONTINUOUS COFFEE STATION</b> <i>Botanicals Foyer</i>
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\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.



## **POLICY GROUP**

### **Draft Agenda Meeting of CSLF Policy Group**

Barbara N. McKee  
Tel: 1 301 903 3820  
Fax: 1 301 903 1591  
*CSLFSecretariat@hq.doe.gov*



## CSLF IS GOING GREEN\*

### DRAFT AGENDA MEETING OF CSLF POLICY GROUP

*Note by the Secretariat*

#### Background

The Secretariat, after coordinating with Policy Group delegates for agenda topics, has developed the draft Agenda for the Carbon Sequestration Leadership Forum Policy Group meeting to be held 25 October 2011 in Perth, Australia.

#### Action Requested

The Policy Group is requested to approve the Agenda of the Policy Group meeting.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.



CSLF-P-2012-01

Draft: 09 October 2012

Prepared by CSLF Secretariat

## CSLF IS GOING GREEN\*

### AGENDA CSLF Policy Group Meeting Perth, Australia October 25, 2012

**07:30-12:00 Registration**  
*Astral Foyer*

**08:30-12:30 Policy Group Meeting**  
*Astral 1 & 2*

**1. Opening Statement**

*Charles McConnell, Policy Group Chair, United States*

**2. Host Country Welcome**

*Margaret Sewell, Head of Clean Energy and Environment Division,  
Department of Resources, Energy and Tourism, Australia*

**3. Introduction of Delegates**

*Delegates*

**4. Adoption of Agenda**

*Charles McConnell, Policy Group Chair, United States*

**5. Review and Approval of Minutes from Beijing Meeting**

*Charles McConnell, Policy Group Chair, United States  
Barbara McKee, Director, CSLF Secretariat*

CSLF-P-2011-09

**6. Review of Beijing Meeting Action Items**

*Charles McConnell, Policy Group Chair, United States  
Barbara McKee, Director, CSLF Secretariat*

**Policy Group Task Force Reports**

**7. Report on Capacity Building**

*Tone Skogen, Norway*

CSLF-P-2012-02

**8. Report from Financing CCS Task Force**

*Bernard Frois, France*

CSLF-P-2012-03

**10:45-11:00 Refreshment Break**  
*Astral Foyer*

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

**9. Policy Roundtable: Advancing CCUS in a Time of Challenge**

- International Collaboration to Advance Demonstration Projects
- Policies For Advancing CCUS

Discussion Moderator: *James Wood, United States*

Presentation: *Barry Jones, Global CCS Institute*

Presentation: *Ashok Bhargava, Asian Development Bank*

Presentation: *Juho Lipponen, International Energy Agency*

**12:30-13:30 Lunch**

*Astral Foyer*

**13:30-15:00 Continuation of Meeting**

**11. Policy Roundtable (Continued)**

Discussion and Action Recommendations

*Delegates*

**15:00-15:15 Refreshment Break**

*Astral Foyer*

**15:15-17:30 Continuation of Meeting**

**CSLF Business**

**12. Election of Policy Group Chair**

*Barbara McKee, Director, CSLF Secretariat*

*Delegates*

CSLF-P-2012-04

**13. Review of 2013 CSLF Ministerial Concept Paper**

*Delegates*

CSLF-P-2012-05

**14. Selection of 2013 Ministerial Steering Committee**

*Delegates*

**15. New Business**

*Delegates*

**16. Closing Remarks/Adjourn**

*Charles McConnell, Policy Group Chair, United States*

**19:00-21:00 Dinner**

*Matilda Bay Restaurant ([www.matbay.com.au](http://www.matbay.com.au))*

*(hosted by West Australian Department of Mines and Petroleum)*

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.



## **TECHNICAL GROUP**

### **Draft Agenda Meeting of CSLF Technical Group**

Barbara N. McKee  
Tel: 1 301 903 3820  
Fax: 1 301 903 1591  
*CSLFSecretariat@hq.doe.gov*



## CSLF IS GOING GREEN\*

### DRAFT AGENDA MEETING OF CSLF TECHNICAL GROUP

*Note by the Secretariat*

#### Background

The Secretariat, after coordinating with the Technical Group Executive Committee, has developed the draft Agenda for the Carbon Sequestration Leadership Forum Technical Group meeting to be held 25 October 2011 in Perth, Australia.

#### Action Requested

The Technical Group is requested to approve the Agenda of the Technical Group meeting.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.

# Carbon Sequestration leadership Forum

CSLF-T-2012-10

Draft: 14 September 2012

Prepared by CSLF Secretariat

[www.cslforum.org](http://www.cslforum.org)



## CSLF IS GOING GREEN \*

### AGENDA CSLF Technical Group Meeting Perth, Australia 25 October 2012

**07:30-12:00 Registration**  
*Astral Foyer*

**09:00-10:45 Technical Group Meeting**  
*Astral 3*

**1. Opening Remarks**

*Trygve Riis, Technical Group Chair, Norway*

**2. Host Country Welcome**

*Clinton Foster, Chief Scientist, Geoscience Australia*

**3. Introduction of Delegates**

*Delegates*

**4. Adoption of Agenda**

*Trygve Riis, Technical Group Chair, Norway*

**5. Review and Approval of Minutes from Bergen Meeting**

*Trygve Riis, Technical Group Chair, Norway*

*John Panek, Deputy Director, CSLF Secretariat*

CSLF-T-2012-09

**6. Review of Bergen Meeting Action Items**

*Trygve Riis, Technical Group Chair, Norway*

*John Panek, Deputy Director, CSLF Secretariat*

**7. Report from Secretariat**

*John Panek, Deputy Director, CSLF Secretariat*

**8. CCS Projects in Australia**

*Wayne Calder, General Manager,*

*Low Emissions Coal and CO<sub>2</sub> Storage Branch,*

*Department of Resources, Energy and Tourism, Australia*

**10:45-11:00 Refreshment Break**  
*Astral Foyer*

- 11:00-12:30 Continuation of Meeting**
- 9. Report from Projects Interaction and Review Team** CSLF-T-2012-11  
*Clinton Foster, Australia*
- 10. Approval of Projects Nominated for CSLF Recognition**  
*Project Sponsors*
- 12:30-13:30 Lunch**  
*Astral Foyer*
- 13:30-15:00 Continuation of Meeting**
- 11. Update on 2013 CSLF Technology Roadmap** CSLF-T-2012-12  
*Trygve Riis, Technical Group Chair, Norway*  
*John Panek, Deputy Director, CSLF Secretariat*
- 12. Update on Technical Group Action Plan** CSLF-T-2012-13  
*John Panek, Deputy Director, CSLF Secretariat*
- 13. Report from Technical Challenges for Conversion of CO<sub>2</sub> EOR to CCS Task Force**  
*Stefan Bachu, Canada*
- 14. Report from CO<sub>2</sub> Utilization Options Task Force** CSLF-T-2012-14  
*Darren Mollot, United States*
- 15. Report from Monitoring Geologic Storage for Commercial Projects Task Force** CSLF-T-2012-15  
*Trygve Riis, Norway*
- 15:00-15:15 Refreshment Break**  
*Astral Foyer*
- 15:15-16:30 Continuation of Meeting**
- 16. Report from Technical Gaps Closure Task Force** CSLF-T-2012-16  
*Richard Aldous, Australia*
- 17. Status of Proposed CSLF Liaison with ISO** CSLF-T-2012-17  
*John Panek, Deputy Director, CSLF Secretariat*
- 18. Review of 2013 CSLF Ministerial Concept Paper** CSLF-T-2012-18  
*John Panek, Deputy Director, CSLF Secretariat*
- 19. Date and Location of Next Technical Group Meeting**  
*John Panek, Deputy Director, CSLF Secretariat*  
*Sergio Persoglia, Italy*
- 20. Planning for 2013 Technical Workshop**  
*John Panek, Deputy Director, CSLF Secretariat*  
*Sergio Persoglia, Italy*  
*Stefan Bachu, Canada*
- 21. Election of Technical Group Chair and Vice Chairs** CSLF-T-2012-19  
*John Panek, Deputy Director, CSLF Secretariat*  
*Delegates*
- 22. New Business**  
*Delegates*

**23. Action Items and Next Steps**

*John Panek, Deputy Director, CSLF Secretariat*

**24. Closing Remarks/Adjourn**

*Trygve Riis, Technical Group Chair, Norway*

**19:00-21:00 Dinner**

*Matilda Bay Restaurant ([www.matbay.com.au](http://www.matbay.com.au))*

*(hosted by West Australian Department of Mines and Petroleum)*

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**POLICY GROUP  
TECHNICAL GROUP**

**Draft Agenda  
Joint Meeting of CSLF Policy and Technical Groups**

Barbara N. McKee  
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Fax: 1 301 903 1591  
*CSLFSecretariat@hq.doe.gov*



## CSLF IS GOING GREEN\*

### DRAFT AGENDA JOINT MEETING OF CSLF POLICY AND TECHNICAL GROUPS

*Note by the Secretariat*

#### Background

The Secretariat, after coordinating with Policy and Technical Group delegates for agenda topics, has developed the draft Agenda for the CSLF Joint Meeting of the Policy and Technical Groups to be held 26 October 2012 in Perth, Australia.

#### Action Requested

The Policy Group and Technical Group are requested to approve the Agenda of the Joint Meeting of the Policy and Technical Groups.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.



## CSLF IS GOING GREEN\*

### AGENDA

#### CSLF Joint Policy and Technical Group Business Meeting Perth, Australia 26 October 2012

#### 08:30-10:30 Joint Policy and Technical Group Meeting

*Astral 1 & 2*

**1. Opening Remarks**

*Charles McConnell, Policy Group Chair, United States*

**2. Adoption of Agenda**

*Charles McConnell, Policy Group Chair, United States*

**3. Review and Approval of Minutes from Beijing Meeting**

*Charles McConnell, Policy Group Chair, United States*

*Barbara McKee, Director, CSLF Secretariat*

CSLF-P/T-2011-03

**4. Review of Beijing Meeting Action Items**

*Charles McConnell, Policy Group Chair*

*Barbara McKee, Director, CSLF Secretariat*

**5. Report from the Policy Group**

*Charles McConnell, Policy Group Chair, United States*

**6. Report from the Technical Group**

*Trygve Riis, Technical Group Chair, Norway*

**7. Review and Approval of Proposed Projects**

*Trygve Riis, Technical Group Chair, Norway*

**8. Report from the Task Force on Risk and Liability**

*George Guthrie, Co-Chair, United States*

*Bernard Frois, Co-Chair, France*

CSLF-P/T-2012-02

**9. Update on Nagaoka CO<sub>2</sub> Storage Project**

*Koji Hachiyama, Director, Global Environmental Partnership  
and Technologies Office, METI, Japan*

**10. New Business**

*Delegates*

#### 10:30-10:45 Refreshment Break

*Astral Foyer*

**10:45-13:30 Continuation of Meeting**

**11. Advancing CO<sub>2</sub> Utilization: A Policy and Technical Roundtable**

CO<sub>2</sub> Utilization Options: Markets, Technologies and Economics

*Trygve Riis, Technical Group Chair, Norway (Moderator)*

*David Cooling, Technical Manager, Alcoa of Australia Ltd.*

*Stefan Bachu, Distinguished Scientist – CO<sub>2</sub> Storage, Alberta Innovates – Technology Futures, Canada*

*Sizhen Peng, Deputy Director General, The Administrative Centre for China's Agenda 21, Ministry of Science and Technology, China*

*Ahmed Al-Eidan, Senior Petroleum Engineer, Saudi Aramco, Saudi Arabia*

*Darren Mollot, Director, Clean Energy Systems, Office of Fossil Energy, United States Department of Energy*

Discussion

*Delegates*

**12. Roundtable: Outreach on Critical Issues**

*Moderator: James Wood, Deputy Assistant Secretary for Clean Coal, Office of Fossil Energy, United States Department of Energy*

*Public Relations Firm: Victoria Osborne, Striker Communications, United States*

*Project Representative: Dominique Van Gent, South West Hub Project, WA Department of Mines and Petroleum, Australia*

*Community Outreach: Bill Spence, Shell, Netherlands*

*Expert on CCUS Communications: John Nayton, Nayton Communications, Australia*

**13. Closing Comments / Adjourn**

*Charles McConnell, Policy Group Chair, United States*

**13:30-14:30 Lunch**

*Astral Foyer*

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.



## **POLICY GROUP**

### **Revised Draft Minutes of the CSLF Policy Group Meeting**

**Beijing, China  
20-21 September 2011**



## CSLF IS GOING GREEN\*

MINUTES OF THE CSLF POLICY GROUP MEETING  
BEIJING, CHINA  
20-21 SEPTEMBER 2011

*Note by the Secretariat*

### Background

The Policy Group of the Carbon Sequestration Leadership Forum held a business meeting on 20-21 September 2011, in Beijing, China. Initial draft minutes of this meeting were compiled by the CSLF Secretariat and were circulated to the Policy Group delegates for comments. Comments received were incorporated into this revised draft. Presentations mentioned in these minutes are now online at the CSLF website.

### Action Requested

Policy Group delegates are requested to approve these revised draft minutes.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.



## REVISED DRAFT Minutes of the Policy Group Meeting

Beijing, China

Tuesday and Wednesday, 20 and 21 September 2011

### LIST OF ATTENDEES

#### Policy Group Delegates

Chairman:	Charles McConnell (United States)
Australia:	Ann Boon, Margaret Sewell
Brazil:	Daniel Falcon Lins
Canada:	Marc D'Iorio, Milenka Mitrović
China:	Li Xin, Sizhen Peng
European Commission:	Wiktór Raldow
France:	Bernard Frois
Germany:	Hubert Höwener, Peer Hoth
Italy:	Liliana Panei
Japan:	Hirotsada Bessho, Shigenori Hata
Korea:	Byong Ki Park, Wonchang Yang
Mexico:	José Miguel González Santaló
Netherlands:	Paul van Slobbe
Norway:	Tone Skogen, Kristoffer Stabrun
Poland:	Janusz Michalski
Saudi Arabia:	Abdulmuhsen Alsunaid, Abdullah AlSarhan
South Africa:	Muzi Mkhize, Faizel Mulla
United Arab Emirates:	Bader Al Lamki, Keristofér Seryani
United Kingdom:	Jeremy Martin, James Godber
United States:	James Wood

#### Technical Group Chairman

Trygve Riis

#### CSLF Secretariat

Barbara McKee, Jeffrey Price, Richard Lynch, Jeffrey Jarrett, Adam Wong, Kathryn Paulsgrove

#### Observer Participants

Brazil:	Marcelo Ketzer (Chairman of the CSLF Task Force on CCUS in the Academic Community)
United Kingdom:	Jeff Chapman (Co-chair of the CSLF Stakeholders Forum)
Clinton Foundation:	Tony Wood
Global CCS Institute:	Barry Jones
International Energy Agency:	Juho Lipponen
World Bank:	Natalia Kulichenko-Lotz

**Tuesday, 20 September**

## **1. Opening Remarks**

Policy Group Chairman Charles McConnell welcomed participants. He thanked the participants for their commitment to the CSLF, the Chinese hosts for their hospitality, Barbara McKee and the Secretariat for the hard work organizing the conference, and the various task forces for their work that would be reported in the meeting. He said that CCS was at a turning point in the policies and practices that needed to be implemented and in the commercial scale projects that were about to be launched leading to commercial deployment. Chairman McConnell also introduced himself, providing background on the 34 years he spent in industry at Praxair and the Battelle Memorial Institute where he was developing a business related to the geologic storage of carbon dioxide (CO<sub>2</sub>), particularly related to Enhanced Oil Recovery (EOR).

Chairman McConnell said that there was a need to embrace a new term – Carbon Capture Utilization and Storage (CCUS) – to address applications such as EOR that make productive use of CO<sub>2</sub> in order to provide a bridge into CCS. It is necessary to provide economic benefit and an incentive for industry to invest because CO<sub>2</sub> storage alone does not yet provide adequate incentive in the current global economic environment. It is also vitally important to reduce the cost of capture and to effectively communicate to the public about the need for CCUS. All this is necessary so that the coming decade of research, development and demonstration actually succeeds in enabling global deployment.

## **2. Introduction of Delegates**

Chairman McConnell asked the Policy Group delegates seated at the table to very briefly introduce themselves, which they all did.

## **3. Adoption of Agenda**

Barbara McKee, Director of the CSLF Secretariat, stated that the Agenda was prepared based on recommendations from the Policy Group and items that resulted from the last Policy Group Meeting and she asked that the Agenda be approved. The Agenda was approved without change.

## **4. Review and Approval of Minutes from Warsaw Meeting**

The draft Minutes of the previous Policy Group meeting held in Warsaw, Poland in October 2010, had been circulated for comment to the Policy Group prior to the meeting. The final draft, which incorporated comments received, had been posted on the CSLF website. The Minutes were approved without further change.

## **5. Review of Warsaw Action Items**

Barbara McKee, Director of the CSLF Secretariat, reviewed the status of the Action Items. She stated that most of the Action Items had been completed and that Bernard Frois, Chairman of the Task Force on Financing CCS, would inform us of the status of one of those Action Items, the study of trigger points for CCS investment.

Chairman Frois stated that the study was to address trigger points for mobilizing investment. Trigger points were understood as potential show stoppers for investment and the most significant of these is a lack of clear policy on CO<sub>2</sub>. Other important issues

are regulatory frameworks, attractive returns for investors and performance based on commercial-scale systems. These conclusions are based on several workshops on financing, information sharing with financial experts with the Global CCS Institute and coordination with the World Bank.

Another Action Item that was outstanding was a communications roundtable. This would need to be implemented at a later meeting.

### **Policy Group Task Force Reports**

#### **6. Capacity Building Task Force Report**

Task Force Chairman Abdulmuhsen Alsunaid of Saudi Arabia reported on the Capacity Building Task Force. He noted that an understanding was reached at the Warsaw meeting as to the responsibilities of the Capacity Building Task Force and the Capacity Building Governing Council and that work has been proceeding based on that understanding. A joint report by both the Task Force and the Governing Council is included in the notebook provided to delegates. In addition to the projects noted in that report, two additional projects, one for Mexico and one for China, were approved by the Task Force and recommended for funding to the Governing Council in the Task Force meeting in the morning prior to the Policy Group meeting. The Task Force is also requesting that developing country Members submit further requests for capacity building. In addition, some of the activities of the Task Force on CCS in the Academic Community may also have the potential to involve capacity building.

#### **7. Report from the Capacity Building Governing Council**

Capacity Building Governing Council Chairman Tone Skogen of Norway reported that CSLF donor countries have committed approximately US\$3 million to the CSLF Capacity Building Fund, which is administered by the Secretariat. The governance of the Fund is performed by the Capacity Building Governing Council, which has developed a Terms of Reference for its operation.

To date, a total of 14 requests for assistance have been received from developing country CSLF Members, two of which were subsequently withdrawn. A total of eight capacity building projects in four countries have been approved to date and will be conducted by the CSLF. Four proposals are also in development and a couple of other projects are also in the pipeline, but have not yet been received. About US\$1 million is still available for further projects. Projects approved so far include:

- Brazil – training program for CCS and monitoring in the offshore environment;
- China – CCUS website and information sharing workshops;
- Mexico – project to educate professors in CCS; and
- South Africa – workshops and conferences on CCS and a study on the impacts of CCS on national priorities.

Discussions are also underway for a project with India and another project with Brazil. Even though projects may be held in one country, they are open to CSLF participants from other Members.

Delegates made several comments on the capacity building activities. It was noted that the CSLF had been holding capacity building workshops for over five years and these provided the impetus for the current program, which is intended to be driven by the needs of the recipient country. The need to share information developed for CSLF capacity

building activities among Members was also noted. Delegates from the countries receiving capacity building assistance also thanked the donor countries and the CSLF and stated that they believed the projects would benefit their countries. Asked what she would like to see changed, Tone Skogen stated that she would like to see more applications for capacity building projects.

The need for further funding to continue the Capacity Building Program was also discussed. The Secretariat and the Capacity Building Governing Council were directed to work to raise further money for the CSLF Capacity Building Fund. In response, Barbara McKee asked that Policy Group delegates provide the names and contacts of organizations that could potentially donate to the CSLF Capacity Building Fund.

## **8. Communications and Public Outreach Task Force Report**

Task Force Chairman John Grasser of the United States stated that the Task Force was following a strategic plan and that the goal of the strategic plan was to address the barriers to public awareness and acceptance of CCS technology. The principal objectives of the strategic plan were to raise visibility of the CSLF, engage key audiences, meet CSLF Strategic Plan requirements and achieve the objectives at low or no cost. He noted that this Task Force had been very active over the past year. The Task Force had developed DVDs and a communications kit and talking points on CCS for use by CSLF Members. This includes a standard speech and a Power Point presentation. The Task Force provides news clips to CSLF Members and stakeholders on a daily basis and has developed an event recognition agreement that conference and meeting sponsors can use to request CSLF co-sponsorship. The CSLF is now starting to use social media, including Twitter and Facebook. All of this is done by the United States Department of Energy with no budget from the CSLF.

Chairman McConnell asked delegates how often they or their colleagues used the information produced by the Task Force. Several delegates indicated that they used informational materials produced by the Task Force and found it useful. This initiated a more general discussion on communications about CCS. It was pointed out that opponents of CCS are often well-funded and, in some places, the public fears geologic storage. The marketplace for messaging about CCS, however, is not homogeneous and there are different audiences with varied interests and opinions and this varies by country. One opportunity for communications is seen as science journalists. The performance of planned large-scale demonstrations may also influence public attitudes. The fact that CCS is being developed and demonstrated globally (and not just in a single country) is seen as a positive message. An issue that also needs to be addressed is that people ask how they specifically benefit when a CCS project is to be located in their local communities. The difficulties that engineers and other technical people have communicating with the public in terms the public understands were also discussed.

Barbara McKee noted that the IEA and the Global CCS Institute also have communications activities and suggested closer coordination in this area.

## **9. Financing CCS Task Force Report**

Task Force Chairman Bernard Frois of France reported on the work of the Financing CCS Task Force. This Task Force was created two years ago and focuses its work on CCS at commercial scale in both developing and developed countries. The Task Force has held four successful roundtables on financing CCS. These involved people with considerable relevant expertise from law firms, insurance companies and banks, as well as industry.

The Task Force has had a number of findings. One finding was that people in different types of organizations involved in CCS do not talk to each other and that was one achievement of the roundtables. A key finding was also the differences among projects and that no one financing method or incentive would work for all. Problems and solutions differ. Moreover, money was not the only issue; regulatory frameworks are absolutely essential. Clear policies are needed. CCS is predicted to be cost-competitive with other sources of low-carbon power such as on or offshore wind, solar power and nuclear in the EU in the early 2020s. However, costs are considerable, but rewards are not clear and all risks must be addressed. In the roundtables, funding models in different parts of the world were presented, in particular by the Asian Development Bank, the World Bank, Alberta, Japan, and several private companies. Each example shows the value of adapting tools to regional and project features. Rather than waiting for the perfect first step on CCS, it is critically important to launch CCS demonstration projects and build confidence in the technology and improve the understanding of its value.

After the presentation and at the request of Chairman McConnell, James Wood of the United States Department of Energy described the CCUS projects in his portfolio in terms of how those became financeable. Mr. Wood said that eight projects have moved forward over the last year from an early stage of analysis to construction, FEED studies or detailed estimates. Two of these projects were polygeneration involving the creation of value through the sale of electricity, urea fertilizer and CO<sub>2</sub> for EOR. Other projects included industrial projects with high-concentration CO<sub>2</sub> emissions and off-take agreements for CO<sub>2</sub> for EOR or methanol. While EOR was used for several of the projects; however, it was not seen as a total solution and will not be used in the FutureGen project. It is now also estimated that 85 billion barrels of unrecovered oil could be recovered through CO<sub>2</sub> used for EOR in the United States. That may also be an opportunity in China. In response, several delegates pointed out that not every country has an opportunity for EOR using CO<sub>2</sub>.

## **10. Report from the Task Force on CCUS in the Academic Community**

Task Force Co-Chairman Marcelo Ketzer of Brazil reported on the Task Force's activities. The objective of the Task Force's activities was to identify courses in the area of CCS and Climate Change inside the academic programs currently available in universities worldwide. Courses were mapped in the Americas; Europe; Africa (South Africa); Asia (Japan, Korea); and Oceania (Australia, New Zealand). A new annex on China is to be added to the report. Differences were found in number and types of courses offered in each country. These courses were identified through an internet search of university websites. For each university, all the offered courses were summarized on tables in accordance with four themes: (i) Capture; (ii) Storage; (iii) Environment; and (iv) Economy, Social, Political and Legal aspects. The methodology has an important limitation. This work was done searching the web, using tools such as Google. This is not necessarily complete or accurate. Delegates were asked to take this document to their own countries and contacts in order to validate and improve this document. Maintaining this document will be an ongoing effort because there will always be new courses and others will no longer be offered.

After the presentation, the discussion centered on how CCUS-related courses were identified, differences among courses offered in different countries, and how the information gathered could be used.

## 11. Report and Approval of Proposed Projects

Trigve Riis, Chairman of the Technical Group, described six projects that were being recommended by the Technical Group for recognition by the CSLF. These projects were:

Project	Type	Nominators
Jämschwalde	Oxycombustion Pilot (30 megawatts) with no storage	Germany, European Commission
Zero Emissions Porto Tolle (ZEPT)	Post-combustion (660 megawatts) with saline formation storage	Italy, European Commission
CGS Europe	Collaborative project involving knowledge transfer and information exchange to facilitate large-scale CCS deployment in EU member states and associated countries	France, Italy
SaskPower Integrated CCS Demonstration at Boundary Dam Unit 3	Integrated project (110 megawatts) with post-combustion capture and utilization of CO <sub>2</sub> for EOR	Canada, United States
Rotterdam Opslag en Afvang Demonstratieproject (ROAD)	Integrated CCS chain project (250 megawatts) with post-combustion capture. CO <sub>2</sub> pipelined 25 km to saline aquifer storage site beneath North Sea seabed	Netherlands, European Commission
CO <sub>2</sub> Capture Project – Phase 3	Partnership of seven major energy companies working to advance the technologies that will underpin the deployment of industrial-scale CO <sub>2</sub> Capture and Storage (CCS)	United Kingdom, United States

The Policy Group approved these projects for recognition by the CSLF.

*The Meeting was adjourned for the day.*

## **Wednesday, 21 September**

Chairman McConnell opened the meeting and called on the Secretariat to summarize the Policy Group meeting on the previous day.

### **12. Summary of Previous Day's Session**

Secretariat Director Barbara McKee gave a brief summary of the discussion held on the previous day covering the four Task Force reports and the recognition of projects.

In discussing the report of the Task Force on CCUS in the Academic Community, which had extensively identified courses on CCUS, Ms. McKee stated that identification of the professors who teach the courses could have even more value than identifying the courses. The Task Force should consider how a network of these professors could be assembled, perhaps using the internet. The goal would be to enable them to communicate with each other in order to exchange ideas, improve courses, and spread the teaching of CCUS. This could provide valuable support to CCUS and to the CSLF. Since this is capacity building on a global scale, it should be coordinated with the Capacity Building Task Force. There was consensus that this would be an action item for the Task Force on CCUS in the Academic Community.

### **Updates from Collaborating International Organizations**

#### **13. IEA CCS Activities Update**

Juho Lipponen of the IEA Secretariat, the Head of the IEA's CCS Unit, described its activities. He said that while energy demand and CO<sub>2</sub> emissions continue to grow rapidly, the role of CCS is currently very limited, but critical in order to address climate change. The IEA has developed a work programme with activities in several different areas, including CCS strategy and policy, legal and regulatory, technical and economic, capacity building, outreach and stakeholder relations. He also described several new reports from the IEA, including reports on the Industrial CCS roadmap, incentives for CCS, the IEA Model CCS Regulatory Framework, the cost of CCS in power generation, and early commercial plants. He also described the roundtable meetings and workshops that comprise IEA's outreach activities. A number of planned new reports will also cover CCS, including the World Energy Outlook 2011.

#### **14. Global CCS Institute Work Plans**

Barry Jones of the Global CCS Institute gave an update on the work of the Institute. He discussed the work done in four areas:

The Status of CCS. The Institute continues to publish its Global Status of CCS reports. The 2010 edition was published in March and the 2011 edition will be released in October. This is intended as a comprehensive overview of the state of development of large-scale projects around the world and of the technologies that make up the CCS chain, as well as the status of policy, legal and regulatory developments to support CCS. The Global CCS Institute also produces reports which give an overview of the status of CCS in various different technology areas or industry areas. In addition, the Institute works on costs. The Institute maintains a comprehensive database of large-scale integrated projects, which is frequently updated.

Capacity and Policy Development. The Institutes contributes to the CSLF Capacity Building Fund as well as trust funds of the Asian Development Bank and the World

Bank. It also undertakes capacity development initiatives itself focusing on China, India, Malaysia, Indonesia, South Africa, and Mexico. The Institute also conducts baseline studies needed before capacity development projects can be undertaken. The Institute is also active in the regulatory area to complement work done by the IEA. It has produced a Regulatory Test Toolkit, which provides a process for national or provincial government administrations to undertake. The Institute is also actively engaged in the lead up to COP 17 in Durban and has recently gained accreditation as an observer under the UNFCCC process.

Project Support. The Institute supports selected projects in order to share knowledge about project development with the global CCS community, and publishes on its website very detailed reports on aspects of project development. The Institute also shares that information through webinars, workshops and seminars which are conducted in countries around the world, bringing project developers together with interested governments and companies. The Institute has also published a number of aids to public acceptance and public engagement.

Knowledge Sharing. The Institute has a comprehensive knowledge-sharing platform, which comprises a public website with a wealth of information about CCS and other knowledge-sharing methods. The Institute also has specialized communities that have much more specialized needs, for example, a Japanese knowledge-sharing network for very targeted and private discussions among the Japanese membership.

## **15. World Bank CCS Activities Update**

Natalia Kulichenko-Lotz, Senior Energy Specialist of the World Bank's Energy, Transport and Water Department, described the Bank's CCS work program. The World Bank has a trust fund for CCS, established in December 2009, with total contributions of US\$11 million with donations from Norway and the Global CCS Institute. The primary objective is to support capacity- and knowledge-building for developing countries and to facilitate inclusion of CCS in their low-carbon strategies. The work has two components: (1) a country-level component focusing on country- and project-specific activities, and (2) an analytic component. Projects are being undertaken in nine different countries. The analytic component consists of a report on barriers to deployment of CCS in developing countries, studies of specific countries and regions and the development of a financing model for CCS projects. The largest World Bank CCS program is in China and considerable work has been done in China with the China Power Investment Corporation.

## **16. CCUS Action Group Update**

Ann Boone of Australia and James Godber of the United Kingdom gave an update on the activities of the CCUS Action Group. The Action Group consists of governments, businesses, non-governmental organizations and institutes and is led by the governments of Australia and the United Kingdom. The Action Group has made a number of recommendations to advance CCS:

1. Reduce the financial gap;
2. Funding support in developing economies;
3. Develop legal and regulatory frameworks;
4. Acknowledge importance of marine treaty amendments;
5. Share knowledge;
6. Investigate carbon dioxide (CO<sub>2</sub>) storage;

7. Support CCS in industry; and
8. Report on progress.

To date, twelve governments have committed to taking action on these recommendations. The CSLF, Global CCS Institute and IEA are working together to develop a work plan for implementation. The next steps are: CEM 3 Meeting in London in 2012, a report on progress of recommended actions, recommendations from working group on funding support in developing countries and announcements from individual countries.

### **CSLF Planning**

#### **17. Revised CSLF Strategic Plan**

Barbara McKee gave a presentation on the draft Second Update of the CSLF Strategic Plan. Ms. McKee said the plan is being updated because the CSLF Charter term is being extended beyond 2013, CO<sub>2</sub> utilization is being added to the scope of the CSLF activities and there is an increased focus on commercial deployment. The draft plan is being presented now to the Policy Group for approval. In this plan, the CSLF organization is unchanged and the Secretariat continues to provide administrative support and requested activities. Various action plans were developed for the Policy Group, the Technical Group and the Secretariat to address key policy and technical barriers. Specific responsibilities are to be assigned for each Action Plan.

The Second Update of the Strategic Plan was accepted by the Policy Group with one edit requested by China to more accurately refer to the second commitment period of the Kyoto Protocol.

#### **18. Planning for the CSLF Ministerial Roundtable**

Barbara McKee briefly described the planning process for the Ministerial and thanked those involved in the planning, including the Ministerial Steering Committee; Chairman McConnell; the Li Xin, the Chairman of the Chinese National Organizing Committee; the Chinese hosts; and the organizations that prepared papers for the Ministers (the Asian Development Bank, the Global CCS Institute, the Clinton Foundation and the Secretariat staff). She then invited the authors of the papers not from the Secretariat who were present to give brief overviews of their papers. Barry Jones of the Global CCS Institute gave a brief overview of the paper “Status, Gaps and Measures to Close Gaps” prepared by the Institute. Tony Wood of the Clinton Global Initiative gave an overview of the paper “Driving CCUS RD&D Deployment: What Will It Take” prepared by the Clinton Foundation.

Li Xin of China expressed appreciation to the Secretariat and the Ministerial Steering Committee for their work, as well as to those who prepared the papers for the Ministers. He also noted that there were nearly 500 registered participants.

Jeff Chapman of the United Kingdom CCS Association and Co-Chair of the CSLF Stakeholders Forum gave a brief overview of the planned program for the Forum. He also noted that the stakeholders were working on a preliminary definition of CCUS.

## 19. Draft Ministerial Communiqué

Chairman McConnell noted that issues remained to be resolved on the Ministerial Communiqué. The Policy Group went through most of the Communiqué on a line-by-line basis. After discussion, these issues were resolved and a number of final edits were made by the Policy Group and the attached Communiqué was approved.

## 20. New Business

There was no other new business.

## 21. Closing Remarks/Adjourn

Chairman McConnell adjourned the meeting and stated that the Stakeholders Forum would be in the afternoon.

### ACTION ITEMS ARISING FROM THE POLICY GROUP MEETING

Item	Lead	Action
1	Capacity Building Governing Council and Secretariat	Raise further money for the CSLF Capacity Building Fund.
2	Policy Group delegates	Provide the names and contacts of organizations that could potentially donate to the CSLF Capacity Building Fund.
3	Communication and Public Outreach Task Force	Coordinate with the IEA and Global CCS Institute.
4	Policy Group Delegates	Take the report from Task Force on CCUS in the Academic Community to home countries for validation and improvement.
5	Task Force on CCUS in the Academic Community	Consider how a network of professors could be assembled and coordinate with the Capacity Building Task Force
6	Secretariat	Make edits to the CSLF Strategic Plan suggested by China.



## **CARBON SEQUESTRATION LEADERSHIP FORUM**

### **Meeting of the Carbon Sequestration Leadership Forum (CSLF) Ministers**

#### ***Collaborating for a Decade of Research, Demonstration and Deployment on Carbon Capture Utilization and Storage***

#### **Communiqué 22 September 2011 at 1730**

We, the Ministers and Heads of Delegation of the CSLF Members, are convinced that we must advance towards the demonstration and deployment of Carbon Capture Utilization and Storage (CCUS) as early as possible. CCUS is one of the low carbon technology options critical to the global quest to reduce carbon dioxide emissions to the atmosphere. We are committed to taking necessary actions individually and collaboratively to make that happen.

CCUS is a necessary technology essential to enabling us to achieve our climate goals and which has been proven safe and effective in all current demonstration projects and applications around the world. We must urgently increase the number of large CCUS demonstrations to enable the deployment of CCUS commercially by the end of this decade.

We met today to discuss and address the key challenges facing CCUS and identify activities necessary to support further research, development, demonstration and deployment. While it is clear that significant progress is being made on CCUS, challenges remain, but these are challenges that can—and will—be overcome.

#### **Including Carbon Capture and Storage in International Agreements**

Ministers applaud the decision at Cancun to recognize Carbon Capture and Storage (CCS) as a measure in the Clean Development Mechanism (CDM). We call upon delegates to the 17th United Nations Framework Convention on Climate Change (COP 17/CMP 7), to be held in Durban, South Africa, to recognize the key role of CCS as a low carbon technology in mitigating climate change and to expedite the inclusion of CCS as a measure in the CDM and in other appropriate financial mechanisms created to mitigate greenhouse gas emissions.

#### **Building and Financing Commercial-Scale CCUS Projects**

We are fully committed to the CSLF strategy to build and operate multiple successful commercial-scale CCUS project demonstrations by 2020. Many such projects are currently under development. Demonstration projects will initially require a mix of public and private financing. The long term deployment of CCUS projects will require the development of conducive policies in order to underpin the necessary financial investment. We are committed to developing these policies. Recognizing the international economic turmoil and the significant need for financial incentives to realize CCUS, financing will remain a key challenge in developed and particularly in developing countries. Increased international concerted action is needed to overcome this challenge. We today reaffirmed our commitment to work with the private sector to build and finance the needed demonstration projects over the next decade.

## **Building on the Success of the CSLF**

Recognizing the continuing need to address challenges, Ministers agreed to extend the term of the CSLF for an indefinite period beyond its prior expiration date of 2013. While much progress has been achieved since the CSLF was founded in 2003, more remains to be done to enable deployment of this vital suite of low carbon technologies.

Ministers recognize the success of the CSLF in providing governments with an international forum to collaborate and create shared commitments to CCUS research, development, demonstration and deployment. This includes ongoing CSLF initiatives to:

- Share information internationally on important CCUS projects;
- Build the capacity for CCUS in the developing country CSLF Members;
- Explore methods for financing CCUS projects, particularly in developing countries; and
- Develop global roadmaps for research, development and demonstration of CCUS technologies.

We are particularly pleased that a total of 30 active and completed, now expanded to 36, diverse CCS projects throughout the world have now been recognized by the CSLF and are sharing their results globally through the CSLF.

## **Expanding Collaboration through the CSLF**

Ministers agree to extend and amend the CSLF Charter to include facilitation and deployment of technologies for utilization of captured carbon dioxide (CCUS).

## **Importance of Stakeholders and Growing International Collaboration**

We are acutely aware that stakeholders in industry, society and the academic community are critically important to the development and commercial deployment of CCUS. While the CSLF is a means of international collaboration by governments, collaboration at the international level between governments and industry is also vitally important. We applaud the efforts of stakeholders to advance CCUS and to be involved in CSLF activities. We strongly encourage their continued involvement in CSLF.

We also welcome additional international collaborations on CCUS through the International Energy Agency, Global Carbon Capture and Storage Institute, the Clean Energy Ministerial (CEM) and multilateral financial institutions. We believe that the increasing number of such collaborations reflects the growing global recognition of the criticality of CCUS and we see these additional collaborations as complementary to the work of the CSLF. We also strongly encourage coordination among these international collaborations. Further, we acknowledge the CCUS recommendations of the second CEM meeting and we look forward to the implementation of those recommendations.

## **Overcoming the Challenges**

We support strategies for the CSLF to resolve barriers for successful implementation of CCUS projects at a time of significant global economic challenge.

- We will work with the private sector to develop and implement methods to finance projects, including those in developing countries.
- We will work to develop legal and regulatory mechanisms to assure safety and appropriately allocate liabilities between the public and private sectors appropriate to our national circumstances.
- We will strengthen cooperation on both technology and policy in order to reduce the financial costs, to lower the energy penalty and to allay public concerns associated with the deployment of CCUS technologies.
- We commend the CSLF's capacity building initiative, and are pleased to announce funding for 12 projects today.
- We task the CSLF to undertake CCUS development initiatives in sectors such as power generation, industry and enhanced oil and gas recovery.



## **POLICY GROUP**

### **CSLF Capacity Building Program and Fund Progress Report**

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## CSLF IS GOING GREEN\*

### CSLF CAPACITY BUILDING PROGRAM AND FUND PROGRESS REPORT

*Note by the Secretariat*

#### Background

The CSLF Capacity Building Program Plan, approved by the CSLF Policy Group and endorsed by Ministers in 2009, defines the mission of CSLF Capacity Building Program as assisting all CSLF Members to develop the information, tools, skills, expertise and institutions required to implement CCS demonstrations and then move rapidly into commercial operation.

The Program Plan further defines four program initiatives:

- Disseminate practical information;
- Build capacity in emerging economies;
- Assist government and regulatory agencies; and
- Build academic and research institutions for CCS.

Each of the capacity building projects undertaken by the CSLF, as described below, addresses one or more of these program initiatives. The Program Plan also provides a framework for the governance of the CSLF Capacity Building Program through:

- Raising of financial resources for capacity building;
- Financial governance through a Capacity Building Governing Council; and
- Assessment of capacity building needs.

This report, written by the CSLF Secretariat, describes the management of the CSLF Capacity Building Fund established for the implementation of that plan and is a status update for the CSLF Capacity Building Program and Fund.

#### Action Requested

The Policy and Technical Groups are requested to consider the report from the Secretariat on the status of the CSLF Capacity Building Program.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.



## **CSLF Capacity Building Program and Fund Progress Report**

### **CSLF Capacity Building Fund**

A CSLF Capacity Building Fund has been established and is administered by the CSLF Secretariat, which reports on financial matters to the CSLF Capacity Building Fund Governing Council. Contributions committed to the CSLF Capacity Building Fund total US\$2,965,143.75. These include the following:

Australia	US\$ 968,160.00
Canada	US\$ 233,073.75
Norway	US\$ 854,670.00
United Kingdom	US\$ 909,240.00

As of August 31, 2012, a total of US\$2,016,950 has been committed to projects, and undisbursed funds are held on behalf of the CSLF in the United States Treasury. (Since the CSLF is not a legal entity that can enter into contracts, it cannot itself hold or disburse funds.) A more detailed statement of funds is included in this report.

### **Governance of the CSLF Capacity Building Fund**

As specified by the Program Plan, the CSLF Capacity Building Fund Governing Council composed of representatives of significant donors has been established. The Governing Council oversees financial aspects of Capacity Building Program. The Governing Council began its operation by developing a Terms of Reference for its operation and for governance of the CSLF Capacity Building Fund. See Annex 1.

The CSLF Capacity Building Fund Governing Council also developed a procedure for soliciting and evaluating requests for capacity building projects using criteria established by the Capacity Building Task Force. This procedure was implemented from 2010 to 2012 in coordination with the Capacity Building Task Force by soliciting and evaluating requests from emerging economy CSLF Members.

### **Collaborations**

The CSLF is collaborating with the Global Carbon Capture and Storage Institute in the management of its Capacity Building Program and is coordinating its activities with CCS capacity building activities of the World Bank. Various other industrial and academic institutions in Member countries are taking part in CSLF capacity building projects.

## Requests for Assistance

The CSLF Capacity Building Fund Governing Council has received to date a total of 12 requests for projects assistance from emerging economy CSLF Members. These requests were evaluated using the criteria developed by the Secretariat and approved by the Capacity Building Task Force and the CSLF Capacity Building Fund Governing Council.

## Capacity Building Projects

A total of 12 capacity building projects in four countries have been approved to date and either have been or will be conducted by the CSLF. While projects may be held in a specific country, workshops and other events are open to participants from all CSLF Members.

Approved projects include:

### Brazil

- Training Program in carbon capture applied to mineral coal combustion and gasification process. This program will build and develop a knowledge base in the process of carbon capture in Brazil through a training program applied to mineral coal combustion and gasification process. The program brings foreign skilled personnel to instruct local human resources and allows Brazilian researchers to participate in practical trainings at the United States Department of Energy (US-DOE) – National Energy Technology Laboratory (NETL) or institutions with recognized expertise. This project will have three courses divided over two and a half years.
- Develop a training program in the process of CCS in the offshore environment. This program will be for professionals from the oil industry, research institutions, universities and stakeholders in general and is viewed as critical to the sustainable development of Brazil's petroleum industry.
- Develop a knowledge base on environmental impact assessment and CO<sub>2</sub> monitoring technologies. This data base will be used for the development of CCS projects in South America by bringing skilled personal to instruct local human resources and advise on the appropriate technology and instrumentation necessary for a specific project. The first course, a basic one, was held in July 2012 and was titled "Understanding Carbon Capture and Storage."

### China

- Develop website on Carbon Capture Utilization and Storage Technologies. This project is establishing the first website focusing on CCS technologies and its development in China. The aims are to serve as a platform to share information and knowledge on technology advancements and good practices and to educate the public. The project has been initiated, and is being translated into English.
- Workshop on experience sharing among CCS demonstration and pilot projects. This workshop was held in July 2012 in Beijing, China. It focused on CCS experience sharing in China and served as a platform of exchange and discussion within China and internationally. Participants were representatives of government departments, academia, industrial stakeholders and NGOs.

- Workshop on legal and regulatory issues for CCS technology development. The themes of the workshop introduce the role of regulatory and enabling environment for CCS development, experiences of developed countries and how China may move forward. Participants are representatives of government departments, academia, industrial stakeholders and NGOs. The workshop is expected to take place in October 2012 in Beijing, China.
- Exploring CCUS Legal and Regulatory Framework in China. This project aims to explore the CCUS legal and regulatory issues in China through an empirical perspective. The project also plans to raise awareness among relevant stakeholder groups, with an aim to promote the establishment of such a regulatory framework and to facilitate the implementation of future CCUS demonstration projects in China.
- Roadmap: CCUS Financing in China. This project aims to address CCUS challenges by formulating the financial roadmap for CCUS development and demonstration in China and spreading information to key stakeholders.

### Mexico

- Introduce CCS into academic programs. This project was held in March 2012 and educated professors and graduate students on carbon capture, utilization and storage through two workshops. The first workshop focused on “CO<sub>2</sub> Geological Storage and Enhanced Oil Recovery,” while the second workshop was on “CO<sub>2</sub> Capture.” The project will also send three individuals from Mexico to attend the Greenhouse Gas Control Technologies (GHGT)-11 Conference in November 2012 in Kyoto, Japan.
- Three Internships on CCS. This proposal will link qualified Mexican personnel to international projects with similar background, objectives, and operations to demonstration projects around the world. Mexico is interested in CO<sub>2</sub> monitoring strategies and techniques and one form of obtaining such experience is via this proposed internship. The Secretariat is in the process of determining and identifying the governmental instrument which would allow the transfer of funds for this project.

### South Africa

- Conduct workshops and conferences during South Africa’s CCS week. Two workshops were held in October 2011 to disseminate information on CCS to relevant stakeholders.
- Impacts of CCS on South African national priorities beyond climate change. The aim of this study is to improve the understanding of how CCS impacts South Africa’s national priority issues beyond CO<sub>2</sub> mitigation and climate change, such as sustainable development, improved local infrastructure, job creation and protection, poverty alleviation, and social upliftment.

## **Annex 1**

### **CSLF Capacity Building Programme Fund Draft Terms of Reference for the Governing Council**

#### **1. Introduction**

1.1 At the CSLF Ministerial Meeting in London in October 2009, Ministers and the CSLF Policy Group approved the CSLF Programme Plan for Capacity Building. The CSLF Capacity Building Programme (the “Programme”) is to be supported financially by the CSLF Capacity Building Programme Fund (the “Fund”). Although the Fund is open to all CSLF Members, the expectation is that the distribution of financial contributions received should focus on emerging economy CSLF Members and represent a wide geographical spread.

1.2 The purpose of the CSLF Capacity Building Fund Governing Council (the “Council”) is to assure that the Fund is spent wisely and appropriately. These Terms of Reference provide the framework for governance of the Council.

#### **2. Membership of the Governing Council**

As of December 3, 2010, CSLF Members who are members of the Council include Australia, Brazil, Canada, Mexico, Norway, Saudi Arabia, the United Kingdom, and the United States. Future membership of the Council is to consist of: (1) representatives from each CSLF Member that have made a financial contribution to the Fund of over a threshold amount of US\$ 100,000.00, (2) the Chair of the CSLF Capacity Building Task Force, and (3) representatives of the CSLF Secretariat, who are non-voting Council Members.

#### **3. Meetings**

The Council is to meet as needed, at least once a year, at such times and places as the Council members may determine. Meetings may be by teleconference or video conference. The Secretariat is to prepare minutes of all meetings.

#### **4. Leadership**

The Chair and a Vice Chair of the Council are elected from among its members.

#### **5. CSLF Fund for Capacity Building**

5.1 The Fund consists of financial contributions paid into a single account to be used for the purpose of capacity building. Following receipt of a contribution, the Council does not accept or honor conditions or restrictions a donor may seek to impose on how its contribution is to be expended.

5.2 In-kind support for capacity building activities is welcomed, but does not constitute a contribution to the Fund. Additionally, funds a CSLF Member expends on capacity building activities in its own country do not constitute a contribution to the Fund.

5.3 Expenditures from the Fund are to be used for direct expenses related to capacity building activities, as recommended by the CSLF Capacity Building Task Force with input from the Council. The CSLF Secretariat may charge up to 7% (including travel expenses) of the total Fund as a Programme management fee, as approved by the Council.

5.4 The Secretariat is responsible for providing coordination for the Programme, analyses and assessments for both the Capacity Building Task Force and the Governing Council, which are to include both the administrative and financial aspects of the Programme.

5.6 Monies in the Fund shall be held by the United States Department of Energy in an account maintained in the United States Treasury for expenditure as directed by the Council. The Council shall designate (subject to acceptance by the designee): either the Secretariat or another organisation to engage and manage contractors or service providers to implement each individual aspect of the Programme.

## **6. Decision Making and Governance Activities**

6.1 The Council is to develop and approve a budget for the Programme; determine the allocation of the Fund based on recommendations by the Capacity Building Task Force; review administration and management of the Fund; apply the CSLF capacity building strategic plan in funding decisions; review project scope and execution by reviewing CSLF capacity building criteria; provide quarterly account statements and reports to the CSLF Policy Group.

6.2 The Capacity Building Task Force is responsible for capacity building Programme strategic development; recommendation of Programme project locations, activities, and topics; and assuring comprehensiveness and complementarities of Programme activities to the CSLF's overall capacity building objectives.

6.3 All decisions of the Council are to be made on the basis of consensus.

## **7. Observers**

By invitation, observers are welcome to attend meetings of the Council.

## **8. Reporting**

The Secretariat should provide reports twice each calendar year to the Council on the status of the Fund. Each such report should provide:

- Progress reports on the capacity building activities during the preceding six-month period;

- Beginning and ending balances of any accounts within the Fund;
- Amounts of financial contributions and expenditures;
- Identity of donors and recipients;
- Quarterly account statements;
- A final expense report for each capacity building activity or event that has been completed; and
- Other information as deemed relevant by the Secretariat or requested by the Council.

**CSLF Capacity Building Funds  
as of September 12, 2012**

	Deposited with DOE	Deposited with GCCSI	
Member Contributions			
Australia	\$ 968,160.00		
Canada	\$ 233,073.75		
Norway	\$ 688,670.00	\$ 166,000.00	
United Kingdom	\$ 909,240.00		
	\$2,799,143.75	\$ 166,000.00	
Total Member Contributions			\$ 2,965,143.75
Expenditures - DOE Federal Admin. Charge (FAC)			
Australia Federal Admin. Charge	\$ 28,198.83		
Canada Federal Admin. Charge	\$ 6,788.56		
Norway Federal Admin. Charge	\$ 20,058.35		
United Kingdom Federal Admin. Charge	\$ 26,482.72		
Total Expenditures DOE Federal Admin. Charge	\$ 81,528.46		\$ 81,528.46
Subtotal			\$ 2,883,615.29
Expenditures - Secretariat Mgmt. Fee			
Australia Secretariat Mgmt. Fee	\$ 65,797.28		
Canada Secretariat Mgmt. Fee	\$ 15,839.96		
Norway Secretariat Mgmt. Fee	\$ 58,422.82		
United Kingdom Secretariat Mgmt. Fee	\$ 61,793.01		
Total Allocated for Secretariat Mgmt. Fee	\$ 201,853.07		\$ 201,853.07
Total Expenditures - Secretariat Mgmt. Fee	\$ 75,501.83		
Total Amount Available for Secretariat Mgmt Fee	\$ 126,351.24		
Subtotal			\$2,681,762.22
	<u>Contractor</u>	<u>Contractor Fees</u>	<u>Total Project Cost</u>
Expenditures for Projects			
Brazil Priority 1 - Training Program in CCS	USEA	\$25,000.00	\$ 302,450.00
Brazil Priority 2 - Offshore Environment Course	USEA	\$11,000.00	\$ 161,000.00
Brazil Priority 3 - Environmental Impacts Course	USEA	\$13,000.00	\$ 213,000.00
China Priority 1 - Website on CCUS Technology	USEA	\$10,000.00	\$ 60,000.00
China Priority 1 Addition - Translate Website	USEA	None	\$ 50,000.00
China Priority 2 - Demo Exp. Sharing Workshop	USEA	\$6,000.00	\$ 76,000.00
China Priority 3 - CCS Regulatory Workshop	USEA	\$6,000.00	\$ 76,000.00
Mexico Priority 1 - Seminars to Introduce CCS	USEA	\$14,500.00	\$ 93,500.00
S. Africa Priority 1 - CCS Outreach Week	GCCSI	None	\$ 86,000.00
S. Africa Priority 3 - Public Outreach Framework	GCCSI	None	\$ 80,000.00
Total Project Expenditures			\$1,197,950.00
Contingency			\$ 150,000.00
Subtotal Funding Available			\$1,333,812.22
Ring Fenced for Future Project Use			
China Add. Priority 1 - CCUS Leg. & Reg. in China	USEA	\$35,000.00	\$ 285,000.00
China Add. Priority 2 - Fin. CCUS in China		TBD	\$ 200,000.00
India Priority 1 - Training Engineers		TBD	\$ 250,000.00
Mexico Priority 2 - Internships on CCS		TBD	\$ 84,000.00
Total Ring Fenced for Future Project Use			\$ 819,000.00
Total Available for CSLF Capacity Building			\$ 514,812.22



## **POLICY GROUP**

### **Report from Financing CCUS Task Force**

### **Summary of January 2012 and September 2012 Finance Roundtables**

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## CSLF IS GOING GREEN\*

### REPORT FROM FINANCING CCUS TASK FORCE

### SUMMARY OF JANUARY 2012 AND SEPTEMBER 2012 FINANCE ROUNDTABLES

*Note by the Secretariat*

#### Background

The CSLF Financing CCUS Task Force was created in 2009 and focuses its work on CCUS at commercial scale in both developing and developed countries. Since its formation, the Task Force has held several roundtables on financing CCUS, involving people with considerable relevant expertise from law firms, insurance companies, and financial institutions, as well as from industry and government. This document presents a summary of the Task Force's January 2012 and September 2012 Roundtables.

#### Action Requested

The Policy Group is requested to review the Financing CCUS Task Force report

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.

# Report from Financing CCUS Task Force

## Summary of 21 January 2012 Finance Roundtable

The Financial Roundtable held by CSLF in collaboration with Société Générale and the Global CCS Institute (GCCSI) in Paris on January 21, 2012 showed that carbon capture, utilization and storage (CCUS) has triggered a strong interest in various parts of the world. An example of this potential is the first of a kind poly-generation industrial project in Texas, being developed by Summit Energy, selling electricity, CO<sub>2</sub>, and urea with long term contract, indexed or floor price and take or pay!

### Simple Ideas that emerged from January 21 Financial Roundtable

- Projects that are simple (avoiding too many partners along the chain) and with not too large budgets (avoiding, e.g., long & over-dimensioned pipelines) are the best suited for demonstration.
- The idea of an incentive for decarbonized electricity to enable CCUS to compete on a level playing field with other low carbon technologies was shared by several participants.
- Need for avoiding perverse effect from some incentives. Mandating CCUS (e.g., by emission performance standards) before realizing the demonstrators could drive investors away. Also, an emission trading scheme (ETS) is a tool to reduce greenhouse gases at lowest cost, not for supporting emergence of a technology.
- Need for specific incentives for demos BUT also need a vision post-2020.
- Several questions on what do we want to demonstrate with demonstration projects. A frequent answer (especially from financial institutions) is: “the integrated chain” because it has never been done before.
- Transforming transport and storage business into regulated assets could be helpful to create “certainty” for banks.
- Prioritize CO<sub>2</sub> storage from gas fields with high CO<sub>2</sub> content as the CO<sub>2</sub> will need to be stripped and this could generate reliable storage.

## 20 September 2012 Finance Roundtable

### Preliminary notes

(Washington, DC)

All participants had wished a follow-up of the Paris Roundtable. At the CSLF-IEA-GCCSI Workshop on Risks and Liability, it became clear that one of the outstanding roadblocks is the lack of advantages for First Movers. There are no longer early movers' advantages but significant disadvantages. It was decided to hold a roundtable on what should be learned from "First Movers". This meeting took place in Washington D.C. on 20 September. The following preliminary notes are some of the findings that emerged from this Roundtable.

In the US, 5 years ago, the understanding was that large capacity for CO<sub>2</sub> sequestration was expected to be in saline aquifers. EOR was considered as a bridging solution with 20 to 30 years capacity before saline aquifers would offer a replacement solution with much larger capacities. Now EOR is reevaluated with a capacity of up to 100 to 150 years (someone mentioned 200 years) for CO<sub>2</sub> sequestration. Additional oil production through EOR is believed to rise from formerly expected 5% up to 40%. EOR is also expected to be a major issue in Middle East and in China, providing particular value for these countries as it is domestic oil production (US & China).

Real figures on EOR potential are very difficult to get hold of as they impact on evaluation of reserves which are strategic info for O&G companies. But EOR operators need large volumes and good availability of CO<sub>2</sub> which is difficult to start developing if EOR strategic capacities are not made public. US is not ready to provide new financing programs at the level of Billions of dollars. **The only way for CCS to further develop is with clear business plan involving EOR.**

The US has the biggest number of projects in development than any other country or region (28 projects, of which 8 are being operated – GCCSI data base).

- Denbury pays now 40\$/ton CO<sub>2</sub> for EOR. Price is linked to oil price (currently 80\$/barrel).
- A new US proposal on tax incentive that provides a \$10/ton credit for CO<sub>2</sub> used in EOR and \$20/tonne for CO<sub>2</sub> placed directly into secure geological storage.
- It is a fact that shale gas interests has distracted efforts/expectation on EOR but potential is there with advantages:
  - CO<sub>2</sub> is used as a "simple solvent" for EOR;
  - Use of water resources for shale gas are not necessary for EOR with CO<sub>2</sub>
  - Fracturation is not required in EOR with CO<sub>2</sub> as in shale gas.
- In Texas there are no new coal PP project (consequence of integrating the uncertainty on future CO<sub>2</sub> impact from coal PP). Peak price were up to >4000\$/MWh, next summer it is expected to reach 9000\$/MWh .

- Projects which go ahead are those that have more than one revenue (e.g.: long term contract for decarbonised power + contract on CO<sub>2</sub> for EOR + contract for urea) or because it is (incremental) to cost and of strategic nature for future of oil & gas. However, these projects required some equity financing as first of a kind.

### **High level conclusions**

According to GCCSI representative, 8 projects currently under operating conditions providing for the storage of 25 Mton/year. This is more in terms of CO<sub>2</sub> than the impact of the whole renewable program of countries such as the UK or Australia.

- CCS cost are lower than renewable (especially offshore or taking into account impacts of intermittent production) and associated with EOR provide for accrued domestic oil production
- In the US, several large scale CCS projects to come to operating conditions in next 3 to 5 years (2015-2017). CCS stakeholders are already considering next generation of capture technology.
- We must ask the question: can we afford to be wrong on the issue of Climate change? If no there is no reason why we should forbid ourselves to use any technology that allows for CO<sub>2</sub> reductions: CCS is necessary.
- CCS is not to be considered exclusively for coal. Next to come is gas.

# Carbon Sequestration Leadership Forum

CSLF-P-2012-04  
14 September 2012

[www.cslforum.org](http://www.cslforum.org)



## **POLICY GROUP**

### **Election of CSLF Officials**

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## CSLF IS GOING GREEN\*

### ELECTION OF CSLF OFFICIALS

*Note by the Secretariat*

#### Background

As stated in Section 3.3 (a) of the CSLF Terms of Reference and Procedures, CSLF Chairs and Vice Chairs will be elected every three years. The previous election of the Policy Group Chair, Technical Group Chair, and Technical Group Vice Chairs was at the London meeting in October 2009, so the next election has been scheduled for the October 2012 CSLF Annual Meeting in Perth, Australia.

#### Action Requested

The Policy Group is requested to hold an election to select a Chair whose term will run through October 2015. The Technical Group is requested to hold an election to select a Chair and Vice Chairs whose term will run through October 2015.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.

# **Election of Policy Group Chair, Technical Group Chair, and Technical Group Vice Chairs**

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

1. *At least 3 months before a CSLF decision is required on the election of a Chair or Vice Chair a note should be sent from the Secretariat to CSLF Members asking for nominations. The note should contain the following:  
  
Nominations should be made by the heads of delegations. Nominations should be sent to the Secretariat. The closing date for nominations should be six weeks prior to the CSLF decision date.*
2. *Within one week after the closing date for nominations, the Secretariat should post on the CSLF website and email to Policy and Technical Group delegates as appropriate the names of Members nominated and identify the Members that nominated them.*
3. *As specified by Article 3.2 of the CSLF Charter, the election of Chair and Vice Chairs will be made by consensus of the Members.*
4. *When possible, regional balance and emerging economy representation among the Chairs and Vice Chairs should be taken into consideration by Members.*

On 19 June 2012, the Secretariat sent an e-mail to CSLF Policy Group delegates, informing them of the upcoming election of the Policy Group Chair, the Technical Group Chair, and the Technical Group Vice Chairs, and that nominations must be received by the Secretariat no later than six weeks prior to the meeting (i.e., by 12 September 2012).

The following nominations were received by the Secretariat:

- Australia, Japan, Mexico, and Norway have nominated the United States for Policy Group Chair.
- Australia, China, Mexico, and the United States have nominated Norway for Technical Group Chair.
- Australia, China, Mexico, and the United States have nominated Canada for Technical Group Vice Chair.
- Australia, China, Mexico, and the United States have nominated South Africa for Technical Group Vice Chair.
- China, Mexico, and the United States have nominated Australia for Technical Group Vice Chair.



## **POLICY GROUP**

### **Draft Concept Paper for the Fifth CSLF Ministerial Conference**

### **Decision Document**

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## CSLF IS GOING GREEN\*

### DRAFT CONCEPT PAPER FOR THE FIFTH CSLF MINISTERIAL CONFERENCE

*Note by the Secretariat*

#### Background

The first four CSLF Ministerial Meetings were held in Tysons Corner, Virginia, USA in June 2003, in Melbourne, Australia in September 2004, in London, United Kingdom in October 2009, and in Beijing, China in September 2011. A fifth Ministerial Meeting is now proposed, as required every two years under Section 3.2(b) of the Terms of Reference and Procedures.

In their September 22, 2011 Communiqué, following deliberations at the Beijing CSLF Ministerial Meeting, CSLF member country Ministers and Heads of Delegation affirmed that CO<sub>2</sub> Capture, Utilization and Storage (CCUS) is an indispensable element of any effective response to climate change and urged the world to increase the number of large demonstrations to enable the deployment of CCUS commercially by the end of this decade. The Ministers also applauded the decision at last year's United Nations Framework Convention on Climate Change (COP 16) to recognize CCUS as a measure in the Clean Development Mechanism (CDM). The Ministerial Communiqué further observed that the Ministers:

*“...Met today to discuss and address the key challenges facing CCUS and identify activities necessary to support further research, development, demonstration and deployment. While it is clear that significant progress is being made on CCUS, challenges remain, but these are challenges that can—and will—be overcome... We support strategies for the CSLF to resolve barriers for successful implementation of CCUS projects at a time of significant global economic challenge. We will work with the private sector to develop and implement methods to finance projects, including those in developing countries. We will work to develop legal and regulatory mechanisms to assure safety and appropriately allocate liabilities between the public and private sectors appropriate to our national circumstances. We will strengthen cooperation on both technology and policy in order to reduce the financial costs, to lower the energy penalty and to allay public concerns associated with the deployment of CCUS technologies... We task the CSLF to undertake CCUS development initiatives...”*

The Ministers also indicated that they welcomed additional international collaborations on CCUS through the International Energy Agency (IEA) the Global CCS Institute, and the Clean Energy Ministerial (CEM).

Since the last Ministerial Meeting, the CSLF has undertaken many activities in response to Ministerial guidance. A Ministerial Meeting at this time would formally take note of what the CSLF has achieved and recommit to its objectives at the ministerial level, would provide

further guidance, and would greatly strengthen global momentum in moving forward with CCS and CCUS.

After reviewing the deliberations and conclusions of the last Ministerial meeting and considering the current global situation with regard to climate related actions and CCS/CCUS, the CSLF Secretariat has prepared a draft concept paper for the fifth CSLF Ministerial Meeting. This draft concept paper is intended as a starting point for discussions.

### Action Requested

The Policy and Technical Groups are requested to consider the Draft Concept Paper for the fifth Ministerial Conference prepared by the Secretariat and to consider the proposed CSLF Ministerial Meeting.

As stated in the Draft Concept Paper, the strongly suggested theme for this Conference is “The Business Case for CCUS: Carbon Utilization to Meet Energy Sustainability, for Economic Development and to Fight Poverty.” CCUS enables the deployment of CO<sub>2</sub> capture technology even in the absence of forcing carbon legislation or regulation by creating a market driver for the CO<sub>2</sub> as a commodity, especially in CO<sub>2</sub>-EOR applications. EOR is the business driver for catalyzing CCUS, while providing economic drivers for commercial projects. It can improve a country’s balance of trade, increase domestic economic activity, create jobs and promote energy security. International collaboration can assist developing countries in pooling their resources, forming project alliances and pursuing commercial scale CCUS projects.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.

Draft as of 14 September

## Concept Paper

### FIFTH CSLF MINISTERIAL CONFERENCE - 2013

#### 0. Background

This Concept Paper outlines issues, which might be debated, and presents options for the fifth CSLF Ministerial Conference, which is proposed to be held during 2013. The options aim at ensuring visibility to the event, the main issues and practical outcomes while promoting wide and qualified attendance. The last Ministerial Conference identified new opportunities for CCS through CCUS. The fifth Ministerial Conference can build on the conclusions of the fourth Ministerial Conference and the CSLF activities to date; which can continue to grow momentum for CCUS. It can also introduce new momentum and impulse into the CSLF process and the emerging international partnerships.

#### 1. Scope of the Ministerial Conference and Expected Outcome

**a) General Theme:** A general theme is recommended to provide the Conference with mission, focus and guidance. The suggested theme is *“The Business Case for CCUS: Carbon Utilization and Storage to Meet Energy Sustainability, for Economic Development and to Fight Poverty.”* CCUS enables the deployment of CO<sub>2</sub> capture technologies even in the absence of enabling carbon legislation or regulation by creating a market driver for the CO<sub>2</sub> as a commodity, especially in CO<sub>2</sub>-enhanced oil recovery (CO<sub>2</sub>-EOR) applications. CO<sub>2</sub>-EOR is a business driver for catalyzing CCUS, while providing economic drivers for commercial projects. It can improve a country’s balance of trade, increase domestic economic activity, create jobs and promote energy security and environmental sustainability. In addition, CO<sub>2</sub>-enhanced coalbed methane (ECBM) recovery and CO<sub>2</sub>-enhanced gas recovery (EGR) are positioned to further expand market opportunities for CCUS. International collaboration can assist developing countries in pooling their resources, forming project alliances and pursuing commercial scale CCUS projects.

**b) Framework:** According to the CSLF Charter, the purpose of the CSLF is *“to accelerate the research, development and commercial deployment of improved, cost-effective technologies for the separation and capture of CO<sub>2</sub> 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, demonstration and commercial deployment of such technology.”*

The fifth Ministerial Conference will be held in a highly dynamic policy framework. Global policy, strategy, legislation and legal frameworks on climate change remain unresolved in many

countries. While the decision at last year's United Nations Framework Convention on Climate Change (COP 16) to recognize CCUS as a measure in the Clean Development Mechanism (CDM) showed progress, it can be assumed that differences will remain among the parties on how to respond to the global climate challenge. Carbon Capture, Utilization and Storage (CCUS) remain a win-win option in this circumstance.

**c) Energy and Environment Context:** Since the time of the 1997 Kyoto Protocol, there has been only limited global progress in curbing CO<sub>2</sub> emissions. The current global mechanisms have not yet been successful in achieving the broad commercial deployment of CCS. The global recession has partly contributed to the limited progress, as has the high cost of low carbon emission technologies. CCUS offers the potential for being able to make major reductions in carbon emissions, but the current cost of CO<sub>2</sub> capture is high and there is major uncertainty in some countries as to how CCS will be regulated. The purpose of this Ministerial is to identify the best path forward for CCUS in the current political, legislative, regulatory and economic climate. The ideal pathway would be one that is economically viable and makes business sense, even in the absence of legislative and regulatory drivers for CCS.

Ranges of experts and analyses have generally concluded that CCS may be essential to meeting global climate goals. Some global leaders have drawn the same conclusion. Former UK Prime Minister Tony Blair stated that *“developing carbon capture and storage technology is not optional, it is literally of the essence.”*<sup>1</sup> Norway's Prime Minister Stoltenberg remarked, *“With nine billion people expected on the planet in 2050, there is no way we can choose between increased energy production and reduced CO<sub>2</sub> – we have to achieve both. Without CCS, we cannot do it.”*<sup>2</sup> Steven Chu, U.S. Secretary of Energy, in a recent article in Nature magazine wrote, *“If the world is to continue to produce electricity from fossil fuels, the carbon emissions from major point sources will have to be significantly reduced in the coming decades. Carbon capture and storage from coal and natural gas power plants and other major emitters, such as cement and steel plants, will be necessary. Also, the International Energy Agency concluded that a climate strategy with CCS would have approximately half the marginal cost in 2050 of a program lacking CCS technology, and (under IEA's assumptions) global cost savings attributable to CCS would total \$1.3 trillion per year in 2050.”*<sup>3</sup>

The world will be dependent on fossil fuels for the foreseeable future and policy makers throughout the world are increasingly aware of this fact. Developing economies will be the major source of energy demand growth, but all countries need energy for economic and social progress and all countries aspire for supply security and a sustainable fuel mix. CCUS will enable the world to use fossil fuels in a more sustainable way, thus easing shared concerns about development, energy security and social progress. However, CCUS must be commercially viable.

CCS market deployment is confronted with the barriers of high cost, project risks, lack of

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<sup>1</sup> [Breaking the Climate Deadlock, A Global Deal for Our Low-Carbon Future \(speech\)](#), T. Blair, The Climate Group, 2008.

<sup>2</sup> [Whatever happened to carbon capture in the fight against climate change?](http://www.guardian.co.uk/environment/2012/may/09/carbon-capture-storage-climate-change), D. Carrington, *The Guardian*, May 9, 2012, <http://www.guardian.co.uk/environment/2012/may/09/carbon-capture-storage-climate-change>.

<sup>3</sup> [Energy Technology Perspectives - 2008](#), Table 2.5, International Energy Agency, 2008

economic incentives and uncertain legal and regulatory frameworks for carbon dioxide transport, storage and the associated liabilities. CCUS can bridge these barriers, but barriers differ among countries and each country must choose the set of measures that best meets its national objectives and circumstances while at the same time supporting the development of regional and international cooperation and cross-border movement of CO<sub>2</sub>.

**d) Policy Imperative:** The key policy imperative is to reach agreement on a strategy for the broad commercial deployment of CCUS in the current global climate and to accelerate its deployment. Even though the precise nature of the agreement that will emerge is not known, it is expected that substantial cuts in carbon dioxide emissions are likely to be required. It is therefore necessary to ensure that CCUS is market deployable when the global outcomes have been agreed upon.

There is also a need to reaffirm agreement on and a willingness to promote CO<sub>2</sub>-EOR as the key component of CO<sub>2</sub> utilization in an effective CCUS strategy. Using CO<sub>2</sub> for EOR is a promising strategy for the commercial deployment of CCS in the current climate. CO<sub>2</sub>-EOR provides for the use of captured CO<sub>2</sub> from power and other industrial plants to facilitate additional production of crude oil via CO<sub>2</sub>-EOR, and the accompanying revenue from its sale. Governments would also benefit from the increased oil production through increased tax revenues and the availability of such oil from either domestic resources or from other secure sources – all of which would strengthen national and global economies. However, such projects also convey significant technical, economic and environmental risks to their sponsors. An incentives program and legal/regulatory clarity is likely to be required to encourage project sponsors to take on the associated risks, as well as a commitment to invest in R, D, &D projects to bring down the cost of CO<sub>2</sub> capture technology. It is also worth noting that CO<sub>2</sub> storage in depleted oil and gas fields and deep saline formations will be required over time to realize the full CCS mitigation potential and demonstration projects must start now.

**e) Government Action:** Governments need to know when CCUS is commercially available and market deployable. Accordingly, Governments will consider what measures they need to take to ensure or accelerate that availability and deploy ability, including pursuing the actions identified as outcomes from the proposed Ministerial Meeting (see subsection h “**Expected Outcomes**” below).

**f) Key Issues:** Key issues for CCUS market deployment are:

- ❖ **Issue A:** Willingness of countries to invest in the development and demonstration of additional large-scale CCUS projects and to assure the success of ongoing projects. Such investment must be made to bring down the costs of CCS, as well as to improve its maturity. CCS technology immaturity is not frequently highlighted but it is a key impediment. Energy producers continue to be concerned that adding CCS at current technology costs would raise the cost of energy, whether it is electricity or liquid fuel, to the point that they could not pass costs through to the consumer and therefore could not pursue CCS.
- ❖ **Issue B:** Willingness of countries to commit to and invest in a winning CCUS deployment strategy. The issues impeding the commercial deployment of CCS have not changed over the last 15 years, which include high CO<sub>2</sub> capture cost, large scale application of technology, technology immaturity, risk allocation, liability, financing, public acceptance, absence of

binding legislation, regulatory uncertainty and more recently the global economic recession. There is a critical need to adopt a CCUS strategy that can overcome these issues by making a business case for the broad commercial deployment of CCUS. Given the current global situation, the most promising strategy for some countries would be to “kick start” a global CO<sub>2</sub>-EOR business using captured anthropogenic CO<sub>2</sub>.

- ❖ **Issue C:** Willingness of countries to make sufficient and especially timely investment in advancing CO<sub>2</sub> capture and related technology performance and cost. Timely investment is needed in component research and development to reduce parasitic energy consumption (including solvent regeneration, compression, gas separation, and solids management), which leads to components at scale that can be retrofitted on existing installations and integrated with existing demonstrations for the purpose of commercialization.
- ❖ **Issue D:** Willingness of countries to pursue environmental, legislative and regulatory strategies that would eliminate any obstacles and would incentivise the use of captured anthropogenic CO<sub>2</sub> for EOR applications.
- ❖ **Issue E:** Willingness of countries to pursue environmental, legislative and regulatory strategies that would eliminate any obstacles and would incentivise the deployment of CCS systems.
- ❖ **Issue F:** Willingness of countries to aggressively incentivize CO<sub>2</sub> capture to overcome the absence of legislative/regulatory requirements to curb CO<sub>2</sub> emissions from gas power plants. Climate strategies cannot be achieved without deploying CO<sub>2</sub> capture on gas plants as well as all other fossil energy sources.
- ❖ **Issue G:** Willingness of developing countries to invest in and enable the deployment of CCUS in their respective countries.
- ❖ **Generic Issues:** The key generic issues, previously identified by the CSLF, specific to CCS and relevant to CCUS as well include:
  - Need to ensure a level playing field for CCUS technologies with other low carbon or zero carbon technologies.
  - Lowering the cost of capture to commercially and economically practicable levels particularly in electricity generation.
  - Developing public confidence in the integrity of the entire CCUS process.
  - Need to ensure a major consultation and outreach process on CCUS to communicate the need for and the benefits of CCUS.
  - Need to develop, where they do not already exist, appropriate legal/regulatory/fiscal frameworks to address intergenerational management of CCUS systems – the liability issue and who carries liability.
  - Need to make sure that the ongoing work on legal/regulatory/fiscal measures does not constrain pilot, demonstration and commercial projects from being implemented.
  - Because of differing national circumstances, need to develop legal/regulatory/fiscal measures that are largely locally based for managing the use of CCUS technology.
  - Need to maintain a global research effort and public/private partnership.

- The IPCC work could be a policy driver – especially in terms of the technical issues and the creation of community confidence in CCUS.

**g) Priority of Issues:** The issue priorities are in the same sequence as listed in the Issues Section (A to G). This prioritization is consistent with accelerating CCUS through CO<sub>2</sub>-EOR. Countries that can and would wish to utilize tax and other incentives to accelerate CO<sub>2</sub> storage by making captured anthropogenic CO<sub>2</sub> economically attractive for CO<sub>2</sub>-EOR applications are likely to agree with this prioritization.

Countries or constituencies that are unable or unwilling to pursue a CCUS/CO<sub>2</sub>-EOR strategy, but desire to assure early CCS deployment would have to assign an even higher priority to making a large direct investment in multiple large-scale integrated CCS projects to bring down the cost of CCS, increase technology maturity, gain public acceptance and would also have to create a favorable economic, legislative and regulatory environment for their deployment. In this context, the prioritization by such countries would lower the issues which focus on CCS/CO<sub>2</sub>-EOR strategies toward the bottom of the issues list, but the prioritization of the remaining issues would remain as listed in the Issues Section.

**h) Expected Outcomes:** Important desired outcomes from the fifth Ministerial Conference include the following:

- ❖ Reaffirmation that governments will work to create the business case for CCUS.
- ❖ Reaffirmation of the importance of CCUS to a global climate strategy, energy security economic development and fighting poverty. Endorse international collaboration to pursue at least one commercial scale CCUS project in developing countries.
- ❖ Reaffirmation of the need for countries to make the necessary and especially timely investment in research and development on carbon capture technology to bring down its cost.
- ❖ Reaffirmation that all fossil fuels will continue to be used and that CCUS is needed to make them sustainable.
- ❖ Reaching agreement that both oil consumers and producers benefit from EOR.
- ❖ Reaching agreement and issuing statement that CCUS and central power plants are needed to reduce poverty.
- ❖ Reaching agreement on and endorsement of a CCUS strategy that will accelerate the early deployment of CCUS in the current global political, legislative, regulatory and economic environment. This would necessarily have to be a strategy that can succeed even in the absence of binding climate legislation and regulation. For some countries, the winning strategy would be utilizing captured anthropogenic CO<sub>2</sub> and using it for CO<sub>2</sub>-EOR and, potentially, for enhanced gas or coalbed methane production.
- ❖ Reaching agreement on and endorsement of a set of incentives that must be implemented by Governments to achieve the agreed upon strategy, including direct investment and tax credits to reduce the cost of the captured CO<sub>2</sub> into the range required to make CO<sub>2</sub>-EOR

commercially feasible. The additional oil thereby produced should yield revenue streams (such as additional tax revenues) that should offset the cost of the tax credits.

- ❖ Reaching Ministerial commitment to pursue the necessary financial incentives in their respective countries to enable the agreed upon strategy.
- ❖ Reaching Ministerial agreement to promote CO<sub>2</sub>-EOR as the key component of CO<sub>2</sub> utilization for an effective CCUS strategy.
- ❖ Reaching Ministerial agreement to endorse environmental legislative and regulatory strategies that would encourage the use of captured, anthropogenic CO<sub>2</sub> for CO<sub>2</sub>-EOR.
- ❖ Identifying follow-on action for the next Ministerial Meeting to assure a continuity of effort and maximizing the pursuit of opportunities and growing the momentum for CCUS deployment.

## 2. Draft Agenda for the Ministerial Meeting

- a) **Calendar:** The Ministerial Meeting and the related events would develop over three days:
  - i) First Day: Policy and Technical Group Meetings
  - ii) Second Day: Parallel Events: Stakeholder's Dialogue and Outreach Forum. Ministers may wish to be present and possibly participate as speakers at selected sessions.
  - iii) Third Day: Ministerial Forum organized along three main Sessions and a Ministerial Statement.
  - iv) A CCS/CCUS projects exhibition will be organized and maintained for the full duration of the Ministerial Meeting and related events.
- b) **Policy and Technical Group:** Meetings will have their standard agenda and should provide the opportunity to fine tune the Ministerial Statement.
- c) **Stakeholders:** Dialogue would focus on the different but complementary roles of governments and various Stakeholders, social consensus and transparency of information. A joint CCS data collection and information exchange initiative might be advocated to facilitate public understanding, acceptance and support. The Stakeholders' Register might also receive a boost.
- d) **Outreach Forum:** The Forum should gather interest and involvement from non-CSLF participant entities (countries, international organizations and non-industry stakeholders).

## 3. Choice of Chairs, Discussants, and Background Papers

- a) The entire Ministerial Forum will have a Chair and two Co-chairs. Co-chairs will be selected from countries chairing or co-chairing the CSLF Policy and Technical Groups. The Ministerial Forum will have three sessions. Background papers will be prepared addressing the key issues.

b) Tentative titles for the Ministerial Sessions:

Session 1: The Strategic Role of Fossil Fuels and Carbon Capture, Utilization and Storage to Secure a Sustainable Energy Future

Session 2: The Business Case for CCUS and for Advancing Carbon Sequestration

- Presentation by the Global CCS Institute on the opportunities for 4-5 additional large-scale CCUS projects in developed countries, to include both EOR and CCS.
- Presentation by the Asian Development Bank on the opportunities for at least one large-scale CCUS project in developing countries.

Session 3: The CSLF Role for Accelerating CCUS Deployment and to Respond to the Global Challenges, including enabling, facilitating financing and incentivizing large-scale CCUS Projects

- c) The Minister from the hosting country will chair Session 1 and Present the Closing Statement. Ministers from the co-hosting countries will chair Sessions 2 and 3, respectively. A panel would be included in each session and would help to stimulate the discussion. The Panel would include the Chair, a Discussant (or Moderator), and two Ministers or Heads of International Organizations. General discussions will follow. The Chair will make a short summary at the end.
- d) Two to three background papers or discussion documents will be prepared. The papers will set the framework and suggest points for discussion. The papers could be prepared by international organizations such as the International Energy Agency, United Nations Environment Program, World Bank, and World Energy Council. Aspects covered must be central to the topics of the three conference sessions and could include the business case for CCUS (which could include both EOR and CCS), the global energy scene, the long-term energy policy views, the obstacles to investment and opportunities -- including identifying tools and actions to implement and enhance international cooperation.
- e) The specific subjects of the papers could include the following:

- A report on what makes some projects succeed and others fail.
- A paper suggesting creative new ways to finance demonstration projects, perhaps by countries collaborating.
- A paper discussing a possible initiative that could be pursued by developing countries to do a CCUS project in a CSLF developing country that would be of adequate scale technically and of interest to technology vendors, but small enough to be affordable.
- A paper on using CSLF project recognition as a vehicle for further collaboration/information sharing.
- A paper providing information, such as the CURC Roadmap, to convey what needs to be done. The latter paper must:

- Clearly describe the sustained effort, phases, and time needed to make CCUS commercial.
- Discuss environmental policies that would be support or impede the development of critically needed technology.
- Support the need to do projects at scale.
- Discuss the elements of an effective deployment strategy.

#### **4. Stakeholders' Dialogue and Outreach Forum**

- a) The Stakeholders' Dialogue will examine how to promote public/private partnerships (i.e. cooperation between governments and industry) and social acceptance. The Dialogue could be a full day event and could be organized into Sessions. Non-government organizations will have a key role. Ministers may wish to attend and intervene. Each Session will be introduced by a keynote speech. Stakeholders' will be invited by the host country and by the countries participating in the CSLF.
- b) The Outreach Forum will involve countries and international organizations, which are not formal participants in the CSLF.
- c) Stakeholders' discussion as well as Outreach Forum debate will be reported at the Ministerial Forum.

#### **5. Participation in the Ministerial Meeting**

- a) Who should participate: Ministers and their staff, Heads of international organizations, observers, and technical staff.
- b) Issues papers should be circulated in advance. Ministers should know they have a mission.
- c) Identification of global personalities as speakers. Some possibilities include Jeffrey Sachs, IEA Director, Bill Clinton, Head of WEC, Bill Gates, Microsoft and, from India, the heads of Reliance and TATA

#### **6. Organizing Stakeholders while Providing Them with a Role**

The choice of themes is important e.g. opportunities for socially responsible investors, challenges and opportunities for sectors and firms, etc.

#### **7. How to Communicate the Results of the Ministerial Meeting**

A communications strategy is necessary for interacting with the press and the media. Each day should make the news by planning a special news release.

- a) Should take advantage of the EOR industry in Houston and Texas to highlight what can be done for CCUS.
- b) Should emphasize utilization, which should include more than just EOR—chemicals, for example.

- c) Should focus attention on all aspects of CCUS including capture, storage, EOR, and economic and energy security benefits.
- d) Should emphasize the importance of CCS.
- e) All messages need to be carefully crafted and negotiated for broad acceptance.
  - Work with IEA to help support the right messages.
  - Messages need to be consistent with energy ministers, not environmental ministers.

#### **8. Proposals and Guidance Emerging from Recent International Events.**

Relevant international conferences and other events must be reviewed in terms of what role they may play in shaping the outlook for CCS and their results should be assessed for what impact they may have on the Ministerial.

#### **9. Organizing a Technology Expo**

Include a Technology Expo as part of the Ministerial

- a) Special tour and site visits for ministers and media
- b) Have in an area where people congregate (e.g., receptions area)
- c) Highlight US industry, but open to companies from all CSLF members
- d) Highlight both utilization/EOR and CCS (especially benefits and successes)



## **TECHNICAL GROUP**

### **Revised Draft Minutes of the CSLF Technical Group Meeting**

**Bergen, Norway  
12 June 2012**

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## CSLF IS GOING GREEN\*

MINUTES OF THE CSLF TECHNICAL GROUP MEETING  
BERGEN, NORWAY  
12 JUNE 2012

*Note by the Secretariat*

### Background

The Technical Group of the Carbon Sequestration Leadership Forum held a business meeting on 12 June 2012, in Bergen, Norway. Initial draft minutes of this meeting were compiled by the CSLF Secretariat and were circulated to the Technical Group delegates for comments. Comments received were incorporated into this revised draft. Presentations mentioned in these minutes are now online at the CSLF website.

### Action Requested

Technical Group delegates are requested to approve these revised draft minutes.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.



**DRAFT**

## Minutes of the Technical Group Meeting

Bergen, Norway

Thursday, 12 June 2012

### LIST OF ATTENDEES

#### Delegates

Australia:	Clinton Foster (Vice Chair), Richard Aldous
Brazil:	Paulo Negrals Seabra
Canada:	Stefan Bachu
China:	Ping Zhong, Xiaochun Li
Denmark:	Søren Frederiksen
European Commission:	Jeroen Schuppers
France:	Didier Bonijoly, François Kalaydjian
Germany:	Jürgen-Friedrich Hake
Italy:	Giuseppe Girardi, Sergio Persoglia
Japan:	Ryo Kubo
Korea:	Chong Kul Ryu, Chang-Keun Yi
Netherlands:	Paul Ramsak
Norway:	Trygve Riis (Chair), Jostein Dahl Karlsen, Tone Skogen
Poland:	Elżbieta Wróblewska
Russia:	Mikhail Puchkov
Saudi Arabia:	Ahmed Aleidan
South Africa:	Tony Surridge (Vice Chair)
United Kingdom:	Philip Sharman
United States:	Joseph Giove, Grant Bromhal

#### Representatives of Allied Organizations

IEA GHG: Tim Dixon

#### CSLF Secretariat

John Panek, Richard Lynch

#### Invited Speakers

Menno Dillen, Research Director, Geophysics and Reservoir Technology Department, SINTEF, Norway

Gunnar Sand, Program Manager, SINTEF and UNIS, Norway

Robert Finley, Director, Advanced Energy Technology Initiative, University of Illinois, United States

Scott McDonald, Biofuels Development Director, Archer Daniels Midland, United States

Vince White, Research Associate, Energy Technology, Air Products and Chemicals, United Kingdom

**Observers**

China:	Mingyuan Li; Xiuzhang Wu
Korea:	Chonghun Han
Norway:	Arne Graue; Anne Kristen Kleiven; Claude Olsen; Åse Slagtern
United Kingdom:	Mark Crombie
United States:	Chris Babel; Mike Holmes; Jeff Jarrett; Ed Steadman

**1. Chairman's Welcome and Opening Remarks**

The Chairman of the Technical Group, Trygve Riis of Norway, called the meeting to order, welcomed the delegates and observers to Bergen, and introduced Vice Chairs Clinton Foster of Australia and Tony Surridge of South Africa.

Mr. Riis provided context for the meeting by mentioning that this was one of the Technical Group's most ambitious and wide-ranging meetings, including both a project visit and a technical workshop on CO<sub>2</sub> capture. In that regard, he mentioned that there was much work to do, with four new task forces having formed and the Technical Group's Action Plan moving forward. Additionally, delegates at this current Technical Group meeting would be reviewing three new projects that have been nominated for CSLF recognition, and if approved by the Technical Group would then be considered by the Policy Group at its meeting in Perth, Australia in October. Also, in addition to the business items on the agenda, there would be several presentations of interest related to carbon capture and storage (CCS) activities in Norway, which should be enlightening to all present.

**2. Welcome from the Government of Norway**

Tone Skogen, Deputy Director General of the Norwegian Ministry of Petroleum and Energy, welcomed the Technical Group to Bergen and provided a Norwegian Government perspective about deployment of CCS. Norway has ambitious goals for broad deployment of CCS and has decided that all future natural gas-fueled power plants will be CCS-compatible. The Norwegian Government has been proactive about CCS by providing funding through Gassnova and the Research Council of Norway for the CLIMIT program that is working toward accelerating the commercialization of CCS. Norway currently has two large projects (Sleipner and Snøhvit) that are storing, cumulatively, nearly two million tonnes of CO<sub>2</sub> per year in geologic structures beneath the North Sea and Barents Sea, respectively. The Norwegian Government has also closely cooperated with industry partners for carbon capture, utilization and storage (CCUS) development, and one result of this is the CO<sub>2</sub> Technology Centre at Mongstad which is a large-scale testing facility for CO<sub>2</sub> capture technologies.

Ms. Skogen closed her remarks by stating that in order for CCUS to succeed, public funding is needed for the first commercial-scale CCUS demonstration projects and that public-private cooperation is essential for success. Also, knowledge sharing and international collaboration is vital to enhance CCUS prospects globally.

**3. Introduction of Delegates and Observers**

Technical Group delegates and observers present for the session introduced themselves. Nineteen of the twenty-five CSLF Members were present at this meeting, including representatives from Australia, Brazil, Canada, China, Denmark, the European Commission, France, Germany, Italy, Japan, Korea, the Netherlands, Norway, Poland,

Russia, Saudi Arabia, South Africa, the United Kingdom, and the United States. Observers representing China, Korea, Norway, the United Kingdom, and the United States were also present.

#### **4. Adoption of Agenda**

The Agenda was adopted with the understanding that Bjørn-Erik Haugan's presentation on "CCS in Norway" would be presented during the June 13 visit to the CO<sub>2</sub> Technology Centre Mongstad project instead of at the Technical Group meeting. Also, the item on "Update on 2012 and 2013 CSLF Technology Roadmaps" was moved to near the end of the meeting.

#### **5. Approval of Minutes from Beijing Meeting**

The Technical Group minutes from the September 2011 meeting in Beijing, China, were approved as final with two minor changes to correct misspellings.

#### **6. Review of Action Items from Beijing Meeting**

John Panek of the CSLF Secretariat reported that all action items from the Beijing meeting had been completed. The Risk Assessment Task Force's Phase II Final Report was not sent out to delegates, but instead was brought before the Technical Group later in the meeting.

#### **7. Report from CSLF Secretariat**

John Panek gave a brief presentation on the November 2011 Global CCS Institute (GCCSI) / CSLF Project Integration Workshop in London. In all, there were about 50 attendees and the key feature of the Workshop was the large amount of interaction, not only between presenters and the audience, but also amongst the presenters themselves. The key messages from the Workshop were that technology integration is a real issue and that it is important to strike a proper balance between plant operation and integration, and that more work is needed in several areas, including plant heat/cooling in the CO<sub>2</sub> capture process, integration of environmental control technologies (i.e., SO<sub>x</sub>, NO<sub>x</sub>, and CO<sub>2</sub> removal) to maximize efficiency, identifying and understanding scale-up risks for CO<sub>2</sub> capture technologies, and determining the impacts of CO<sub>2</sub> composition/impurities as they apply to CO<sub>2</sub> transport and storage.

Mr. Panek called on Richard Lynch of the Secretariat to summarize the January 2012 CCUS Financing Roundtable (co-sponsored with the Global CCS Institute and Société Générale) in Paris. Mr. Lynch stated that the meeting had about 40 attendees, many from the international banking sector. The key message from the Roundtable was that the large first-of-a-kind "lighthouse" CCUS projects are having great difficulty achieving financial closure due to perceived risk. For these "lighthouse" projects, integration risk is a major concern. These first-of-a-kind projects are not so much meant to demonstrate individual technologies at large scale as to demonstrate their integration. Costs are high, in part, because technology suppliers are adding large contingency factors, largely in the form of additional onsite technical assistance. Also, warranties are being required by project sponsors that may not be necessary for future commercial-scale projects. Simplicity is best for financing plans. More moving parts in a financing plan increase the chance of show-stopping issues. However, added project complexity, in the form of polygen production, increases the revenue stream and helps alleviate project risk. This built-in contradiction is an issue that may not be easy to solve. As a result of this risk, no

“lighthouse” project can be reasonably expected to go forward without substantial governmental support (direct and/or from incentives) to close financing gaps.

Mr. Panek then called on Tony Surridge of South Africa to describe the October 2011 CCS Week in South Africa. Dr. Surridge stated that the event was hosted by the South African Centre for Carbon Capture and Storage (SACCCS) and organized by SACCCS and South Africa’s Department of Energy with financial support from the CSLF Capacity Building Fund. The objective of the event was to disseminate information around local and international CCS research and development and to showcase CCS activities currently underway in South Africa. The conference focused on the South African and the southern Africa regional CCS activities that are currently underway. There were four technical workshops focusing on important aspects of CCS: CO<sub>2</sub> injection projects; CCS legal and regulatory framework; CCS public engagement; and CCS risk assessment. Dr. Surridge stated that the main achievements of the week were the dissemination of CCS knowledge and experience among stakeholders and interested parties, as well as undertaking the first steps into risk assessment and public engagement.

Mr. Panek concluded the Secretariat Report by very briefly summarizing the March 2012 Capacity Building Workshops that were held in Mexico City, also financially supported by the CSLF Capacity Building Fund and organized by the CSLF, Mexico’s Institute of Engineering (UNAM), and Mexico’s National Autonomous University. This was an extended event, staged over two weeks, with the first week centered on geologic storage of CO<sub>2</sub> and the second week focused on CO<sub>2</sub> capture.

## **8. Update from Norway’s CO<sub>2</sub> Field Lab Project**

Menno Dillen, Research Director in SINTEF’s Geophysics and Reservoir Technology Department, gave a detailed presentation on the CSLF-recognized CO<sub>2</sub> Field Lab Project. This is a pilot-scale project, located at Svelvik, Norway, which is investigating monitoring technologies for CO<sub>2</sub> leakage detection in a well-controlled and well-characterized permeable geological formation. Relatively small amounts of CO<sub>2</sub> are being injected to obtain underground distribution data that resemble leakage at different depths. The main objective is to assure and increase CO<sub>2</sub> storage safety by obtaining valuable knowledge about monitoring CO<sub>2</sub> migration and leakage. The outcomes from this project will help facilitate commercial deployment of CO<sub>2</sub> storage by providing the protocols for ensuring compliance with regulations, and will help assure the public about the safety of CO<sub>2</sub> storage by demonstrating the performance of monitoring systems.

Mr. Dillen stated that Phase 1 of the project ran from September 2009 to January 2011, and that activities in the first project phase included a baseline seismic survey in November 2009 as part of the site characterization, drilling and logging of a 300-meter deep exploration well, and updating models based on the logged data from the well. Phase 2a, which began in May 2011, has so far included a shallow CO<sub>2</sub> injection test with extensive sampling to develop a record of the behavior of the injected CO<sub>2</sub>. A deep permeability test is planned to begin in September 2012. Initial results from the Phase 2a shallow injection test reinforce the necessity of proper site characterization, as part of the monitoring system missed the plume of CO<sub>2</sub>. Based on this result, one learning from the project is that a diverse monitoring system will provide the greatest capability and flexibility for CO<sub>2</sub> leakage and migration measurements. Mr. Dillen closed his presentation by affirming that the CO<sub>2</sub> Field Lab Project is providing a good environment to test and compare monitoring technologies under controlled conditions. Mr. Dillen

noted that the nearby community was very positive about the work, and that funding was approximately €10 million for 4-5 years.

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

The PIRT Chair, Clinton Foster of Australia, gave a presentation that summarized the previous day's PIRT meeting, which resulted in the following outcomes:

- The Illinois Basin – Decatur Project, the Illinois Industrial Carbon Capture and Storage Project, and the Air Products CO<sub>2</sub> Capture from Hydrogen Facility Project were all approved by the PIRT and sent forward to the Technical Group for its consideration.
- A plan for future updates of the CSLF Technology Roadmap (TRM) was developed.
- A proposal for updating and simplifying the CSLF Project Submission Form and Gaps Analysis Checklist was discussed, but no firm conclusion was reached. As a result, approval of a revised Form and Checklist has been deferred until the next PIRT meeting, in October 2012 at the 2012 CSLF Annual Meeting in Perth, Australia.

Discussion on the TRM was temporarily deferred, as it was an agenda item for later in the meeting.

## 10. Approval of Projects Nominated for CSLF Recognition

### Illinois Basin – Decatur Project (*nominated by United States and United Kingdom*)

Robert Finley, Director of the Advanced Energy Technology Initiative in the Illinois State Geological Survey at the University of Illinois, gave a presentation about the Illinois Basin – Decatur Project. This is a large-scale carbon CCS demonstration project of the Midwest Geological Sequestration Consortium (MGSC), one of the seven Regional Partnerships organized by the United States Department of Energy (DOE). The project is being led by the Illinois State Geological Survey. Up to 1 million metric tons of CO<sub>2</sub> will be injected over a 3-year period into a Cambrian-age geological formation called the Mt. Simon Sandstone at a rate of 1,000 tonnes per day and a depth of about 2 kilometers. After three years, the injection well will be sealed and the reservoir monitored using geophysical techniques. The CO<sub>2</sub> is being captured from the fermentation process used to produce ethanol at Archer Daniels Midland Company's corn processing complex in Decatur, Illinois, in the United States. The Mt. Simon Sandstone is the thickest and most widespread saline reservoir in the Illinois Basin, with a CO<sub>2</sub> storage capacity estimated from 11 to 151 billion tonnes. Monitoring, verification, and accounting (MVA) efforts began in 2008 and include tracking the CO<sub>2</sub> in the subsurface, monitoring the performance of the reservoir seal, and continuous checking of soil, air, and groundwater both during and after injection. Operational injection of CO<sub>2</sub> began in November 2011.

The goal of this project is to demonstrate the potential of the Mt. Simon Sandstone to be a significant CO<sub>2</sub> geologic sequestration reservoir for the Illinois Basin region in the United States. The key research targets for MGSC's large-scale injection test relate to CO<sub>2</sub> injectivity and volumetric storage capacity of the saline reservoir, the integrity of the seals to contain the CO<sub>2</sub> in the subsurface, and the entire process of pre-injection characterization, injection process monitoring, and post-injection monitoring to understand the fate of the injected CO<sub>2</sub>. The focus is on demonstration of CCS project development, operation, and implementation while demonstrating CCS technology and reservoir quality.

After brief discussion, there was consensus by the Technical Group to recommend CSLF recognition for the project.

Illinois Industrial Carbon Capture and Storage Project (*nominated by United States and France*)

Scott McDonald, Biofuels Development Director for project sponsor Archer Daniels Midland, gave a presentation about the Illinois Industrial Carbon Capture and Storage Project. This is a large-scale project, also located in Decatur, Illinois, which will collect up to 3,000 tonnes per day of CO<sub>2</sub> from the Archer Daniels Midland ethanol production plant in Decatur and store it in the Mt. Simon Sandstone. Mr. McDonald noted that the captured CO<sub>2</sub> generated by this industrial process was more than 99% pure, in contrast to the lesser purity of CO<sub>2</sub> streams from power plants. Project scope includes the design, construction, demonstration, and integrated operation of CO<sub>2</sub> compression, dehydration, and injection facilities, and MVA of the stored CO<sub>2</sub>. Engineering, permitting, and construction activities are underway and are scheduled to conclude by mid 2013. Operation of the CO<sub>2</sub> capture and storage facility will begin during the second half of 2013.

The goals of this project are to design, construct, and operate a new CO<sub>2</sub> collection, compression, and dehydration facility capable of delivering up to 2,000 tonnes of CO<sub>2</sub> per day to the injection site; to integrate the new facility with an existing 1,000 tonnes of CO<sub>2</sub> per day compression and dehydration facility to achieve a total CO<sub>2</sub> 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<sub>2</sub>; and to develop and conduct an integrated community outreach, training, and education initiative. Unlike the Illinois Basin – Decatur Project, which focuses on research aspects of large-scale CCS, this project is intended to be an industrial commercialization project. A significant feature of the project is its “negative carbon footprint”, meaning that there will be a net reduction of atmospheric CO<sub>2</sub>. There is also a possibility that CO<sub>2</sub> from this and other Archer Daniels Midland ethanol facilities could be used in the future for enhanced oil recovery (EOR), as the Illinois Basin is a petroleum producing region.

After brief discussion, there was consensus by the Technical Group to recommend CSLF recognition for the project.

Air Products CO<sub>2</sub> Capture from Hydrogen Facility Project (*nominated by United States, Netherlands, and United Kingdom*)

Vince White, Research Associate in Air Products and Chemicals Inc.’s Energy Technology Division, gave a presentation about the Air Products CO<sub>2</sub> Capture from Hydrogen Facility Project. This is a large-scale commercial project that will demonstrate a state-of-the-art system to concentrate CO<sub>2</sub> from two steam methane reformer (SMR) hydrogen production plants, and purify the CO<sub>2</sub> to make it suitable for sequestration by injection into the existing West Hastings Field oil reservoir as part of an ongoing EOR project. To accomplish this, Air Products plans to retrofit its two Port Arthur SMRs with two vacuum swing adsorption (VSA) systems to separate the CO<sub>2</sub> from the process gas streams at these facilities so that the CO<sub>2</sub> can be compressed, dried, and delivered by pipeline. Air Products’ carbon capture processes would convert the initial gas streams, which contain more than 10% CO<sub>2</sub>, to greater than 97% CO<sub>2</sub> purity with negligible impact on the efficiency of hydrogen production. The technology would remove more than 90% of the CO<sub>2</sub> from the process gas stream.

The commercial goal of the project is to recover and purify approx. 1 million tonnes per year of CO<sub>2</sub> for pipeline transport to Texas oilfields for use in EOR. The technical goal is to capture at least 75% of the CO<sub>2</sub> from a treated industrial gas stream that would otherwise be emitted to the atmosphere. A financial goal is to demonstrate real-world CO<sub>2</sub> capture economics.

After brief discussion, there was consensus by the Technical Group to recommend CSLF recognition for the project. Also, the United States delegation was requested to provide a revised Project Submission Form with enhanced details about this project, and the Secretariat was asked to send this information to all Technical Group delegates.

### **11. Report from Task Force to Assess Progress on Technical Issues Affecting CCS**

The task force Chair, Clinton Foster, gave a brief presentation that described the background and activities of the task force. This task force was established by the CSLF Technical Group on recommendation by the PIRT. The objective was to complement the PIRT's assessment of the CCS readiness of the CSLF-recognized projects. The task force is comprised of four working groups: Capture Technologies (chaired by the United States), Transport and Infrastructure (chaired by Australia), Storage and Monitoring (chaired by Canada), and Integration (developed in cooperation with, and reported by the Global CCS Institute).

Dr. Foster reported that the task force has submitted its final report and recommended that the task force be discontinued. Technical findings from the task force would be used to assist new task forces and also as input for revisions to the TRM. Grant Bromhal of the United States mentioned that a section on Capture Technologies had been completed too late to make it into the final report. After brief discussion, Dr. Foster agreed that the task force final report would be revised to incorporate the updated Capture Technologies section. There was also consensus that the task force be ended. Dr. Foster expressed his appreciation to the chairs of the four working groups and also thanked the Research Council of Norway and the Global CCS Institute for providing additional resources.

### **12. Report from Risk Assessment Task Force (RATF)**

Grant Bromhal, who had recently replaced George Guthrie as RATF Chair, gave a brief presentation that described the background and activities of the RATF. The RATF was formed at the November 2006 Technical Group meeting in London with the mandate to examine risk-assessment standards, procedures, and research activities relevant to unique risks associated with the injection and long-term geologic storage of CO<sub>2</sub>. The RATF Phase I Report, completed in 2009, centered on examination of risk-assessment standards, procedures, and research activities relevant to unique risks associated with the injection and long-term storage of CO<sub>2</sub>. The Phase I Report included an overview of risk assessment methodologies for engineered geologic systems, a literature review of risk assessment for CO<sub>2</sub> storage, identification of key potential risks, an overview of monitoring & mitigation options that support risk assessment, and a summary of ongoing and emerging activities in CSLF countries. One of the recommendations from the Report was that the link between risk assessment and liability should be recognized and considered. As a result, the CSLF Policy Group has formed a Task Force on Risk and Liability which will call on the Technical Group for assistance as needed.

Dr. Bromhal reported that RATF has submitted its Phase II Report, which includes a gaps assessment to identify CCS-specific tools and methodologies that will be needed to support risk assessment and a description of risk-assessment considerations related to

various phases of a CO<sub>2</sub> storage project. Appendices to the report include a collection of five “inFocus” outreach documents (developed by the CSLF Communications and Outreach Task Force) and a paper on “Performance-based Standards for Site Safety and Integrity”. The Phase I Report had also recommended that the RATF gather information on what other organizations are doing in the area of technical risk and also conduct a feasibility assessment of developing general technical guidelines for risk assessment that could be adapted to specific sites and, local needs. However, both these activities were left undone, the former because it was deemed that the result would be a report that would very quickly become obsolete and of marginal use and the latter because the new Task Force on Risk and Liability would most likely include this as part of its mission.

Dr. Bromhal stated his intention of converting the Phase II Report into an article for the *Journal of Greenhouse Gas Control* and concluded his presentation by stating that the RATF had completed its mission and recommended that it be discontinued. There was consensus to end the RATF, and Dr. Bromhal was asked to pursue the idea of publishing the Phase II Report as a journal article.

### 13. Overview of Technical Group Action Plan

John Panek gave a short presentation that summarized progress on the Technical Group Action Plan since it was approved at the 2011 CSLF Ministerial Meeting in Beijing. In all there are twelve separate Actions, and the Secretariat polled Technical Group delegations to determine relative priorities. The highest ranked Action was “Storage and Monitoring for Commercial Projects”, which has since been renamed as “Monitoring Geologic Storage for Commercial Projects”, and a new task force chaired by Norway has formed on this Action.

Mr. Panek stated that three other Actions had also resulted in new task forces: “Technology Gaps Closure” (ranked second highest; new task force chaired by Australia), “Technical Challenges for Conversion of CO<sub>2</sub>-EOR to CCS” (ranked fifth highest; new task force chaired by Canada), and “CO<sub>2</sub> Utilization Options” (ranked eighth highest; new task force chaired by the United States). The highest ranked Actions that do not currently have new task forces are “Risk and Liability” (ranked third highest) and “Energy Penalty Reduction” (ranked fourth highest).

Ensuing discussion did not result in the formation of any additional task forces or suggestions for additional Actions. There was interest in the Action on “Competition of CCS with Other Resources”, but consensus was reached that the Technical Group should wait to see the forthcoming report from a similar IEA GHG study before considering a new task force on this topic. Philip Sharman of the United Kingdom stated that the Actions on “Energy Penalty Reduction” and “CCS with Industrial Emission Sources” were of interest but that he would need to check with the United Kingdom’s Department of Energy and Climate Change (DECC) before he could volunteer to Chair a new task force for either of these. Clinton Foster indicated that the Global CCS Institute had shown some interest in the “Best Practice Knowledge Sharing” Action, and there was consensus that he contact the Institute to determine if it would like to lead a task force. Alternatively, CSLF members could access the Institute’s work in this area. Finally, it was decided that no activity be undertaken on the “Risk and Liability” Action unless/until the Policy Group’s task force in this area requests Technical Group assistance.

Mr. Panek stated that the Secretariat would provide a progress report on the Technical Group Action Plan for the next Technical Group meeting.

#### **14. Report from Technical Challenges for Conversion of CO<sub>2</sub>-EOR to CCS Task Force**

Stefan Bachu of Canada, the Chair of this new task force, gave a short update on its mandate, timeline, and membership. EOR is a proven method for geologic storage of CO<sub>2</sub> and there are currently approximately 120 CO<sub>2</sub>-EOR projects in the world, of which 112 are in the United States. The objective of the task force is to review, compile and report on technical challenges that may constitute a barrier to the broad use of CO<sub>2</sub> for EOR and to the conversion of CO<sub>2</sub>-EOR operations to CCS operations. Dr. Bachu stated that economic and policy barriers are outside the scope of the task force.

Dr. Bachu stated that the task force's intention is to complete its activities and produce a final report in the third quarter of 2013, in time for the next CSLF Ministerial Meeting. Before that, the task force will have finalized its scope (i.e., identified subjects and produced a table of contents) by the 2012 CSLF Annual Meeting in October, produced a first draft of its report in time for the 2013 Technical Group meeting. Task force membership currently consists of Canada (as Chair), China, Norway, Mexico, Saudi Arabia, and the United States. Dr. Bachu mentioned that there was still time for other CSLF delegations to join if they would add to the expertise of the task force.

#### **15. Report from CO<sub>2</sub> Utilization Options Task Force**

Joseph Giove of the United States, the Chair of this new task force, gave a short update on its mandate, timeline, and membership. The purpose of the task force is to identify/study the most economically promising CO<sub>2</sub> utilization options that have the potential to yield a meaningful, net reduction of CO<sub>2</sub> emissions. There will be two phases of activity. The first phase (to be completed by the time of the 2012 CSLF Annual Meeting) will result in a summary of existing information regarding CO<sub>2</sub> utilization options, including a description of the state of each relevant technology and application; a preliminary assessment of the relative value of the utilization option to make a meaningful impact on CO<sub>2</sub> emission reduction; and an indication regarding the economic viability of such technologies. The second phase will provide a more thorough discussion of the most attractive CO<sub>2</sub> utilization options, based on economic promise and CO<sub>2</sub> reduction potential, possibly including an assessment of current and potential economic viability, the CO<sub>2</sub> reduction potential at various price points, the potential for co-production, and a discussion of research, development and demonstration (RD&D) needs.

Mr. Giove stated that the task force was looking at both consumptive and non-consumptive uses for CO<sub>2</sub>, including as feedstock for chemicals and synthetic cement-like materials industries. In the short term, the task force decided the focus should not be solely on EOR, as a different task force already has that mission. As the new Technical Challenges for Conversion of CO<sub>2</sub>-EOR to CCS task force scopes out its mission in greater detail in the future, it will be better known what elements of EOR can/should be covered by the CO<sub>2</sub> Utilization Options task force. Phase 1 activities would include a literature review, and a Phase 1 report is intended to be a deliverable at the upcoming 2012 CSLF Annual Meeting. Task force membership currently consists of the United States (as Chair), China, Germany, Netherlands, Saudi Arabia, South Africa, and the United Kingdom. Mr. Giove mentioned that the task force was open for other participants as well.

#### **16. Report from Monitoring Geologic Storage for Commercial Projects Task Force**

Lars Ingolf Eide of Norway, the Chair of this new task force, was unable to attend so Trygve Riis provided a short update on the scope, schedule, and membership. The

objective of the task force is to perform initial identification and review of new and updated standards for storage and monitoring of injected CO<sub>2</sub>, and the application of such standards should inform CO<sub>2</sub> crediting mechanisms. The planned scope includes identification and review of existing standards for geological CO<sub>2</sub> storage and monitoring on an annual basis; identification and review of existing guidelines for communication with and engagement of involved communities and regulators on an annual basis; identification of shortcomings and/or weaknesses in standards/guidelines; communication of findings to the ISO's CCS Working Group (that has already been established); production of annual summaries of new as well as updated standards, guidelines and best practice documents regarding geological storage of CO<sub>2</sub> and monitoring of CO<sub>2</sub> sites; and following the work of other CSLF task forces related to CO<sub>2</sub> storage.

Mr. Riis stated that the task force's intention was to complete an initial compilation of standards (based on a literature review) in time for the 2012 CSLF Annual Meeting. A final report on standards and guidelines would be finished in the third quarter of 2013, in time for the next CSLF Ministerial Meeting. At that time, a decision would be made on whether to continue the task force, and such a decision could depend on progress made by the ISO's CCS Working Group in this area. Current membership in this task force consists of CSLF delegates and stakeholders from Norway (including the Chair), China, Denmark, the European Commission, France, Germany, the United Kingdom, and the United States. Mr. Riis mentioned that additional members are welcome who can add to the expertise of the task force.

## **17. Report from Technology Gaps Closure Task Force**

Richard Aldous of Australia, the Chair of this new task force, gave a short update on its mandate, timeline, and membership. The purpose of the task force is to identify and monitor key CCS technology gaps and related issues and recommend any R&D and demonstration activities (both short term and long term) that address these gaps and issues. The intention is to build on some of the results from the Task Force to Assess Progress on Technical Issues Affecting CCS, with results from this task force feeding into future versions of the TRM. The planned scope includes determining technology areas and sub-areas of interest, identifying gaps and opportunities in each area, and developing recommendations for faster progress in addressing these gaps. This could possibly include identifying opportunities for international collaboration on technology development.

Dr. Aldous stated that the intention was to have a preliminary report in time for the upcoming 2012 CSLF Annual Meeting that would list technology areas of interest to the task force, and identify and rank technology gaps in each of these areas. By the time of the 2013 Technical Group meeting, the task force would produce a draft report that would focus on the most important gaps, with recommendations how these gaps could be closed. This report would then be finalized by the third quarter of 2013, in time for the next CSLF Ministerial Meeting. Current membership in this task force consists of Australia (as Chair), Korea, Norway, and the United States, and Dr. Aldous stated his preference that each of these CSLF delegations appoint one expert on CO<sub>2</sub> capture and one expert on CO<sub>2</sub> storage.

Ensuing discussion centered on the name of this task force, and there was general agreement that the word 'gaps' was not precise enough, in that 'issues' were also part of the task force's mission. In the end, there was consensus that Dr. Aldous, as Chair of the task force, should determine a more descriptive name for this task force.

## 18. Presentation on the CCS Activities of University Centre in Svalbard

Gunnar Sand, Program Manager for SINTEF and Project Manager of CCS Activities for the University Centre in Svalbard (UNIS) CO<sub>2</sub> Lab, gave a short presentation about the CO<sub>2</sub> Lab and other CCS-related activities on the islands of Svalbard. Mr. Sand pointed out that Svalbard's community of Longyearbyen, at +78°13' latitude and with a population of just over 2,000, is the world's northernmost settlement and as such, makes an excellent research base for studying and monitoring climate change. Svalbard is actually an uplifted part of the Barents Sea and is made up of sedimentary rocks, including coal seams. There is coal mining there and also a coal-fueled power plant, the only one in Norway. The UNIS CO<sub>2</sub> Lab was established in 2007 with a vision of following the CO<sub>2</sub> from the source to the solution, turning Longyearbyen into a high profile green showcase demonstrating the CO<sub>2</sub> value chain, and developing high level field-based university studies in CCS. Mr. Sand stated that the geology of Svalbard is conducive for storage testing of CO<sub>2</sub> from the power plant, and initial activities of the UNIS CO<sub>2</sub> Lab have focused on storage reservoir characterization. Future activities are intended to include medium scale CO<sub>2</sub> injection with several monitoring wells.

Mr. Sand mentioned that the UNIS CO<sub>2</sub> Lab is also a partner in the European 'Euroscoops' Program that is proposing to implement permanent geological CO<sub>2</sub> storage at an industrial scale at five sites in Europe, including Longyearbyen. The activities at Longyearbyen will include developing/refining monitoring and modeling tools, conducting two injection campaigns (using water and gas), and conducting an extensive outreach program. It is anticipated that there will also be a visitor centre established at Longyearbyen to assist in these activities.

## 19. Update on 2012 and 2013 CSLF Technology Roadmaps

Clinton Foster provided a synopsis of the discussion on this topic from the previous day's PIRT meeting. There had been agreement on the overall importance of the TRM and that it needed updating. There has already been agreement, at the 2011 Technical Group meeting in Beijing, that the country-specific information from Module 2 of the TRM would be migrated to the CSLF website. A proposal for a new model of the TRM, based on suggestions by Richard Aldous, would chart CCUS pathways as far into the future as 2050. The current TRM only goes as far as 2020. Dr. Aldous stated that the reason for this lengthened timeline is that some countries have developed CCUS objectives that extend that far into the future. Proposed key elements for the next major revision of the TRM would include an executive summary, a relatively brief module that describes the current state of the technology, a module that describes possible scenarios for meeting long-term CCUS objectives, and a set of recommendations to national governments concerning actions needed to realize the most favorable scenarios. Dr. Foster stated that the intention is that the next major revision of the TRM would be a deliverable at the 2013 CSLF Ministerial Meeting.

There was general agreement that the TRM is one the most important products of the Technical Group, and that the Technical Group should put forth effort into getting a good, major revision completed in time for the next Ministerial Meeting. Ensuing discussion resulted in a consensus that the Technical Group was not yet ready to describe possible CCUS pathways beyond 2020, so the next major revision of the TRM would maintain that timeline. There was also consensus that, because this 2013 TRM would likely be a major undertaking, the Technical Group should focus on that and not produce a 2012 TRM. However, agreement was not reached on what the structure of the 2013 TRM

should be, or the process for completing it. Several suggestions were offered concerning the TRM structure, including that the TRM should conclude with recommendations to policy makers about actions that should be taken to increase the technical knowledge base, which will lead to large scale CCUS deployment by the TRM target dates. Another suggestion was that this major revision of the TRM should be structured much like the one we have now, but not including the country and projects presentation, and with more concise descriptions of technologies.

Dr. Foster recommended that a TRM Steering Committee/Editorial Board, chaired by the Technical Group Chairman, be established to work out all details concerning the structure and schedule, and to oversee the development of the new TRM. There was consensus to do so, and that this new group would also include the Technical Group Vice Chairs, Task Force Chairs, and the CSLF Secretariat. Chairman Riis suggested that possible collaboration with other organizations (primarily the Global CCS Institute) should also be investigated.

## **20. Discussion of Ideas for Future Technical Group Workshops**

Meeting attendees were reminded by Chairman Riis about the CO<sub>2</sub> Capture Interactive Workshop, which would take place in Bergen two days hence. Concerning future workshops, Stefan Bachu proposed that the topic of “Monitoring of CO<sub>2</sub> Storage” would be appropriate as there is knowledge to be gained from the experience of existing projects and from technological developments, and it would make for an interesting, informative, and useful event. After brief discussion, there was consensus for adopting this theme for the next technical workshop, and that it should be held in conjunction with the 2013 Technical Group meeting.

## **21. Date and Location of Next Technical Group Meeting**

John Panek mentioned that the next CSLF Technical Group meeting would be part of the 2012 CSLF Annual Meeting in Perth, Australia. The actual date of the Technical Group meeting will be Thursday, October 25, with task force meetings scheduled for Wednesday, October 24. Preliminary information about the 2012 Annual Meeting is already available at the CSLF website ([www.cslforum.org](http://www.cslforum.org)).

Sergio Persoglia of Italy stated that there was interest in his country to have the 2013 Technical Group meeting and Technical Workshop in Rome, sometime in the first half of the year. Chairman Riis thanked Dr. Persoglia for the information and asked him to further explore this possibility and inform the Technical Group at its next meeting in Perth.

## **22. New Business**

Chairman Riis called on Tim Dixon of the IEA GHG to briefly describe his organization’s recent activities that are relevant to the Technical Group. Mr. Dixon stated that a study had been completed on “Geological Storage of CO<sub>2</sub> in Basalts”, and the final report was available to Technical Group delegates. Mr. Dixon was asked to provide the report to the CSLF Secretariat, and the Secretariat was requested to send the report to all Technical Group delegates. Mr. Dixon also informed the Technical Group that at the November 2011 United Nations COP17 Conference in South Africa, there was agreement that CCS would be included as part of the Clean Development Mechanism (CDM). Mr. Riis thanked Mr. Dixon and stated that this information might possibly be factored into future CSLF activities such as the TRM.

### 23. Review of Consensuses Reached, Action Items, and Next Steps

Consensus was reached on the following:

- The Illinois Basin – Decatur Project, the Illinois Industrial Carbon Capture and Storage Project, and the Air Products CO<sub>2</sub> Capture from Hydrogen Facility Project are all recommended by the Technical Group to the Policy Group for CSLF recognition.
- The Task Force for Assessing Progress on Technical Issues Affecting CCS is discontinued.
- The RATF is discontinued.
- Activity on the “Competition of CCS with Other Resources” Action in the Technical Group Action Plan is deferred pending review of a forthcoming IEA GHG report on this topic.
- Activity on the “Risk and Liability” Action in the Technical Group Action Plan is deferred unless/until there is a request for assistance from the Policy Group’s Risk and Liability Task Force.
- The next major revision of the TRM, planned for completion in time for the 2013 CSLF Ministerial Meeting, would keep the 2020 timeline described in the current TRM.
- There will not be a 2012 version of the TRM.
- The next CSLF Technical Workshop, anticipated during the first half of 2013, will have a “Monitoring of CO<sub>2</sub> Storage” theme.

Action items from the meeting are as follows:

Item	Lead	Action
1	Technical Group Chair	Provide the Technical Group’s recommendation to the Policy Group that the Illinois Basin – Decatur Project, the Illinois Industrial Carbon Capture and Storage Project, and the Air Products CO <sub>2</sub> Capture from Hydrogen Facility Project be recognized by the CSLF.
2	United States	Prepare a revised version of the Project Submission Form for the Air Products CO <sub>2</sub> Capture from Hydrogen Facility Project with enhanced details about the project.
3	CSLF Secretariat	Send the revised Project Submission Form for the Air Products CO <sub>2</sub> Capture from Hydrogen Facility Project to all Technical Group delegates.
4	Chair of Task Force to Assess Progress on Technical Issues Affecting CCS	Revise the task force final report to incorporate the updated Capture Technologies section.
5	Chair of RATF	Pursue the possibility of publishing the RATF Phase II Report as a journal article.
6	Australia	Contact the Global CCS Institute to determine if it would like to lead a new task force on “Best Practices Knowledge Sharing”.
7	CSLF Secretariat	Provide a progress report on the Technical Group Action Plan for the next Technical Group meeting.
8	Chair of Technical Gaps Closure Task Force	Determine a more descriptive name for the task force.

Item	Lead	Action
9	Technical Group Chair	Establish and Chair a TRM Steering Committee/Editorial Board, to also include the Technical Group Vice Chairs, Task Force Chairs, and CSLF Secretariat.
10	Italy	Explore the possibility of Italy hosting the 2013 CSLF Technical Group meeting and next Technical Workshop.
11	IEA GHG	Provide a copy of the IEA GHG final report on “Geological Storage of CO <sub>2</sub> in Basalts” to the CSLF Secretariat
12	CSLF Secretariat	Send the IEA GHG final report on “Geological Storage of CO <sub>2</sub> in Basalts” to all Technical Group delegates.

## 24. Closing Remarks / Adjourn

Chairman Riis thanked the delegates, observers, and Secretariat for their hard work. John Panek expressed the Secretariat’s appreciation to Mr. Riis for acting as meeting host in addition to his Chairman’s role, and Mr. Riis called out Anne Kristin Kleiven, Åse Slagtern, and Aage Stangeland of the Research Council of Norway as the people who helped to make it all happen.

Mr. Riis reminded attendees of the upcoming visit to the CSLF-recognized CO<sub>2</sub> Technology Centre Mongstad Project on Wednesday, June 13<sup>th</sup>, and adjourned the meeting.





## **TECHNICAL GROUP**

### **Simplification of CSLF Gaps Analysis Checklist**

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## CSLF IS GOING GREEN\*

### SIMPLIFICATION OF CSLF GAPS ANALYSIS CHECKLIST

*Note by the Secretariat*

#### Background

Proposed simplification of the CSLF Gaps Analysis Checklist has been the subject of extensive discussions at the Beijing Projects Interaction and Review Team (PIRT) and Technical Group meetings in September 2011 and also the Bergen PIRT and Technical Group meetings in June 2012. In September 2012, the Secretariat sent PIRT delegates a proposal from the PIRT Chair for simplifying the Gaps Analysis Checklist down to a smaller and more manageable number of categories. Responses from PIRT delegates indicated they were overwhelmingly in favor of this simplification, with minor modifications. This paper presents the PIRT Chair's original proposal for simplification of the Checklist, a summary of responses from PIRT delegates on the proposal, and also a comprehensive analysis, done by the PIRT Chair, matching the existing CSLF-recognized projects to the revised Checklist.

#### Action Requested

The Technical Group is requested to review the revised Gaps Analysis Checklist and analysis of CSLF-recognized projects under the revised Checklist.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.

**SEEKING RESOLUTION OF THE SIMPLIFICATION OF *CSLF GAPS ANALYSIS CHECKLIST* THAT ACCOMPANIES THE *CSLF PROJECT SUBMISSION FORM***

**Clinton Foster**

**Chair - CSLF Projects Interaction and Review Team**

**Vice Chair – Australia CSLF Technical Group**

**PROPOSITION**

- That the members of the CSLF Projects Interaction and Review Team (PIRT) vote, out of session, and via reply email, to agree to a simplified version of *CSLF Gaps Analysis Checklist* (the *Checklist*) that accompanies the *CSLF Project Submission Form*.
- The proposed *Checklist* is set out below: it reduces from 7 A4 printed pages to 1 A4 page. Using the simplified categories, all the existing CSLF Projects can be characterised for further analysis (see Attachment).
- With majority agreement of PIRT members, this proposition will be noted at the next PIRT meeting (Perth) and the TG will be asked to both note and confirm the changes at the Perth meeting.

**The proposed Checklist (as submitted to the PIRT meeting in Beijing)**

**GENERAL**

<b>Project Scale</b>	
Feasibility	
R&D	
Pilot	
Demonstration	
Commercial	

**CAPTURE TECHNOLOGIES**

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

**STORAGE (& MONITORING) TECHNOLOGIES**

<b>Storage Complex Type</b>	
Saline formations	
Unconventional reservoirs (e.g. basalt, shale)	
Unmineable coal formations	
EOR and/or EGR	

<b>Storage complex characterization</b>	
CO <sub>2</sub> -water-rock (or coal) interactions	
Impact of the quality of CO <sub>2</sub> on storage	
Improved modelling of complex	
Effects of depth, pressure and stress and CO <sub>2</sub> -rock/water interactions on permeability, injectivity, migration, trapping and capacity	
Pressure management (e.g. production of formation water)	
<b>Monitoring the storage complex including risk assessment</b>	
Development of new or improved CO <sub>2</sub> monitoring technologies	
Improve baseline monitoring and distinguish between natural and anthropogenic CO <sub>2</sub>	
Development of risk minimization/mitigation methods and strategies, including leakage	
Improve well integrity, well abandonment practices, and/or remediation of existing wells	

## TRANSPORT

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

### Background and discussion

- This proposition is an outcome of the Warsaw TG and the action has been discussed at PIRT and TG meetings since 2010: but without clear resolution.
- It became clear from the Working Groups (WGs) of the recently completed Task Force *Assessing Progress on Technical Issues Affecting CCS*, that the *Checklist* that accompanied the *Project Submission Form* was inadequate in that many more gaps/issues were identified by the WGs, but it also raised the questions of:
  - how detailed (or granular) the *Checklist* should be; and
  - what was the purpose of the *Checklist*?
- Both questions have been discussed in CSLF meetings in Edmonton, Warsaw, and Beijing and relevant comments are chronicled below
- Put simply the original purpose of the *Checklist* was to check if gaps (as identified at that time) were being filled by projects put forward for CSLF recognition. But the level of sophistication of the answer to that question has changed, as evidenced by the detailed WGs findings. Moreover, anecdotal evidence to me as PIRT Chair, and to other members of the PIRT and the Secretariat, is that the *Checklist*, as it currently stands, is seen as *too detailed and confusing* and, as a result, not always filled in correctly.
- The simplified list captures the relevant information and allows the CSLF Projects to be categorised (see Attachment)

**CHRONOLOGY OF THE RECENT REVISION OF THE *CSLF PROJECT SUBMISSION FORM* (approved Pau, March 2010) AND THE ATTEMPTS TO SIMPLIFY THE *CSLF GAPS ANALYSIS CHECKLIST* (as empowered Warsaw October 2010; and discussed May 2011 Edmonton; September 2011, Beijing; and Bergen, June 2012)**

**Background – reference documents**

**1. Approval of a revised *CSLF Project Submission Form***

**1.1 March 15-16 Pau, 2010**

<http://www.csforum.org/publications/documents/Pau2010/PIRTSummaryPau0310.pdf>

**March 15-16 Pau**

Other actions by the PIRT at this meeting were:

- Approval of the revised PIRT Terms of Reference
  - Approval of the schedule for updating the CSLF Technology Roadmap
  - Approval of a plan for analyzing CSLF-recognized projects in relation to technology gaps
  - Approval of a proposal for engaging CSLF-recognized projects and attracting new projects, including a CSLF Projects Workshop that would be held some time in the future
  - **Approval of a revised CSLF Project Submission Form**
  - Approval of a recommendation that the CSLF Charter be extended beyond its expiry date of 2013
  - Development of ideas for enhanced collaboration with the IEA GHG and GCCSI, including proposals for new IEA GHG projects
- All of the PIRT's actions were brought forward to the full Technical Group for its consideration.

**2. EXAMINATION OF THE *CSLF GAPS ANALYSIS CHECKLIST***

**2.1 Minutes of the Technical Group Meeting**

**Warsaw, Poland**

**Thursday, 07 October 2010**

<http://www.csforum.org/publications/documents/Warsaw2010/tgMinutesWarsaw1010Final.pdf>

**11. Update of CSLF Project Submission Form**

**Chairman Riis stated that this item had been mostly handled during the previous item, as there had been consensus that the four Working Groups should develop condensed and concise lists of gaps for a revision to the Gaps Analysis Checklist in time for the next PIRT meeting.** After ensuing discussion there was agreement to keep the existing Project Submission Form / Gaps Analysis Checklist for now, while the new Task Force to Assess Progress on Technical Issues Affecting CCS and the PIRT work to develop a revision to the

Form and Checklist, as described earlier. Harry Schreurs proposed that two Checklists are actually needed – the concise Checklist for the Project Submission Form and a “deeper level of granularity” Checklist that can be used to evaluate projects. **There was consensus to adopt this approach, and the four Working Group Chairs were empowered to shorten the existing Checklists as needed to produce the concise versions.**

## 2.2 Edmonton May 2011

<http://www.csforum.org/publications/documents/Edmonton2011/Foster-TG-PIRTReport-Edmonton0511.pdf>

PIRT Meeting Edmonton, May 18, 2011

OUTCOMES (1)

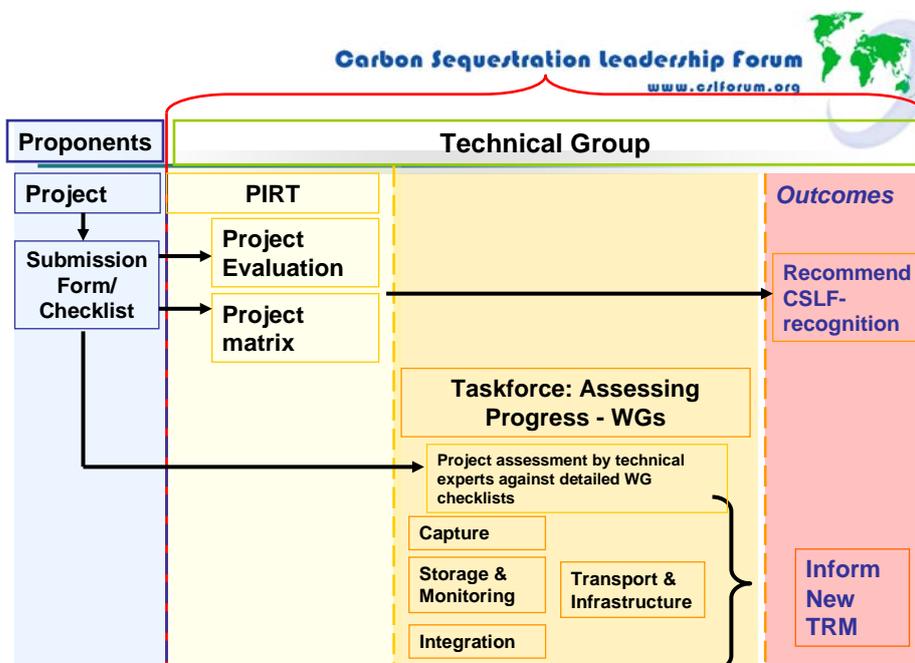
Procedural matters

- Agreed to remove *Taskforce to Assess Progress on Technical Issues affecting CCS* from PIRT – report to TG
- **Will re-examine CSLF Gaps Analysis Checklist as used for Project Submission. Aim to simplify.**
- Discussed technical presentations to the PIRT for CSLF project recognition – reaffirming the PIRT role in recommending projects to the TG

### 2.3.1 Presentation to the PIRT, Beijing 19 September 2012

<http://www.csforum.org/publications/documents/beijing2011/Bachu-ChairmanPresentationPIRT-Beijing0911.pdf>

See PowerPoints 4-11



Roles in CSLF Project Recognition and technology input to TRM

### **2.3.2 Minutes of the Technical Group Meeting Beijing, China Tuesday & Wednesday, 20-21 September 2011**

[http://www.cslforum.org/publications/documents/beijing2011/tg\\_MinutesBeijing0911Final.pdf](http://www.cslforum.org/publications/documents/beijing2011/tg_MinutesBeijing0911Final.pdf)

#### **8. Report from Projects Interaction and Review Team (PIRT)**

The Acting PIRT Chair, Stefan Bachu, gave a presentation that summarized the PIRT's recent accomplishments. At the Edmonton meeting, the PIRT reached an agreement that the Task Force on Assessing Progress on Technical Issues Affecting CCS should be separated from the PIRT, and report directly to the Technical Group. Also at the Edmonton meeting, the PIRT approved two projects for CSLF recognition: the Jänschwalde Project and the Zero Emission Porto Tolle (ZEPT) Project. The PIRT also discussed the need to simplify the CSLF Project Submission Form and Gaps Analysis Checklist.

At the previous day's PIRT meeting, the four projects that were just approved by the Technical Group were initially reviewed and approved by the PIRT. After approval by the Technical Group, the projects then go for review by the Policy Group. **A discussion regarding the level of detail on the CSLF Project Submission Form also occurred. While some argued that the forum should be simpler, there were other arguments to keep it as detailed as possible, particularly if there is a need to uncover what the projects will do and what gaps in knowledge will be address. There was no resolution to the issue, and thus it will be brought up again during the next PIRT meeting.**

#### **2.4 Bergen June 2012 see Power Points 1-7 only**

<http://www.cslforum.org/publications/documents/bergen2012/Foster-UpdateProjectSubmissionForm-PIRT-Bergen0612.pdf>

## Summary of Responses Received from PIRT Delegates to Proposed Simplified Gaps Analysis Checklist

<b>CSLF Member</b>	<b>Adopt Simplified Checklist?</b>	<b>Comments</b>
<b>Australia</b> • Aldous	Yes	
<b>Canada</b> • Bachu	Yes	
<b>Denmark</b> • Frederiksen	Yes	
<b>European Commission</b> • Peteves • Schuppers	Yes Yes	Modify the wording of the 4 <sup>th</sup> “Storage complex characterisation” category to: “Effects of CO <sub>2</sub> -rock/water interactions and induced changes in temperature, pressure and stress on permeability, injectivity, migration, trapping and capacity”.
<b>France</b> • Bonijoly	Yes	
<b>Italy</b> • Girardi • Persoglia	Yes Yes	
<b>Japan</b> • Tanaka	Yes	
<b>Mexico</b> • González-Santaló	Yes	
<b>Netherlands</b> • Ramsak	Yes	
<b>Norway</b> • Riis	Yes	
<b>Poland</b> • Wróblewska	Yes	
<b>Saudi Arabia</b> • Abuleif	Yes	
<b>South Africa</b> • Surridge	Yes	
<b>United Kingdom</b> • Sharman	Yes	Add an additional category for “Depleted Oil/Gas Fields”; reposition the “Transport” section before the “Storage” section.
<b>United States</b> • Bromhal • Mollot	Yes Yes	



- 1 [Alberta Enhanced Coal-Bed Methane Recovery Project \(Project Completed\)](#)
- 2 [CANMET Energy Technology Centre \(CETC\) R&D Oxyfuel Combustion for CO2 Capture](#)
- 3 [CASTOR \(Project Completed\)](#)
- 4 [CCS Belchatów Project](#)
- 5 [CCS Rotterdam](#)
- 6 [CGS Europe Project](#)
- 7 [China Coalbed Methane Technology/CO2 Sequestration Project \(Project Completed\)](#)
- 8 [CO2 Capture Project - Phase 2 \(Project Completed\)](#)
- 9 [CO2 Capture Project - Phase 3](#)
- 10 [CO2CRC Otway Project](#)
- 11 [CO2 Field Lab Project](#)
- 12 [CO2 GeoNet](#)
- 13 [CO2 Separation from Pressurized Gas Stream](#)
- 14 [CO2STORE \(Project Completed\)](#)
- 15 [CO2 Technology Centre Mongstad Project \(formerly European CO2 Technology Centre Mo\)](#)
- 16 [Demonstration of an Oxyfuel Combustion System](#)
- 17 [Dynamis \(Project Completed\)](#)
- 18 [ENCAP \(Project Completed\)](#)
- 19 [Fort Nelson Carbon Capture and Storage Project](#)
- 20 [Frio Project \(Project Completed\)](#)
- 21 [Geologic CO2 Storage Assurance at In Salah, Algeria](#)
- 22 [Gorgon CO2 Injection Project](#)
- 23 [IEA GHG Weyburn-Midale CO2 Monitoring and Storage Project](#)
- 24 [ITC CO2 Capture with Chemical Solvents](#)
- 25 [Ketzin Test Site Project \(formerly CO2 SINK\) \(Project Completed\)](#)
- 26 [Lacq CO2 Capture and Storage Project](#)
- 27 [Quest CCS Project](#)
- 28 [Regional Carbon Sequestration Partnerships](#)
- 29 [Regional Opportunities for CO2 Capture and Storage in China \(Project Completed\)](#)
- 30 [Rotterdam Opslag en Afvang Demonstratieproject \(ROAD\)](#)
- 31 [SaskPower Integrated CCS Demonstration Project at Boundary Dam Unit 3](#)
- 32 [SECARB Early Test at Cranfield Project](#)
- 33 [Zama Acid Gas EOR, CO2 Sequestration, and Monitoring Project](#)
- 34 [Zero Emission Porto Tolle Project \(ZEPT\)](#)



## **TECHNICAL GROUP**

### **2013 CSLF Technology Roadmap Scoping Document**

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## CSLF IS GOING GREEN\*

### 2013 CSLF TECHNOLOGY ROADMAP SCOPING DOCUMENT

*Note by the Secretariat*

#### Background

At the June 2012 CSLF Technical Group meeting in Bergen, Norway, there was consensus that the Technical Group would not produce a 2012 CSLF Technology Roadmap (TRM) and instead focus its efforts and resources on a 2013 TRM that would be a deliverable at the 2013 CSLF Ministerial Meeting. This paper is a scoping document for the 2013 TRM that has been developed by Lars Ingolf Eide of Norway, with input from the CSLF Technical Group Chair, Vice Chairs, and Task Force Chairs.

#### Action Requested

The Technical Group is requested to review the scoping document.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.

# Technology Roadmap (TRM) 2013

## Discussion Note on Content, Scope and Process

### Background

At the meeting of the CSLF Technical Group (TG) in Bergen June 12, 2012, it was decided to revise the TRM. The consensus was that the new document should be short and concise, with focus on technological priorities and recommendations to policy and decision makers with the focus on technology developments that are needed to enable large-scale deployment rather than on scientific gaps. The new TRM should be finalized for the Ministerial meeting scheduled for the fall of 2013.

A steering committee (SC) that will be responsible for the preparation of the new TRM was set up, under the chairmanship of the Chair of the Technical Group. The Steering Committee will set the content of the TRM and will seek ways to have it produced in time for the 2013 CSLF ministerial meeting.

Many barriers to implementation of CCUS are political in nature. Thus, road-mapping CCUS may be considered as much an issue-oriented process as a technology-oriented process, but the availability of advanced technology is an important element of issue-oriented roadmaps. It is suggested that this update of the CSLF TRM will focus on technological solutions to identified barriers, including policy and public engagement issues, which should be included as background. However, the TRM should stay clear of policy issues.

Several roadmaps for CCS have been or will be published, including those by IEA and GCCSI. The CSLF TRM 2013 should, while being cognisant of roadmaps published by other organisations, focus on technology deployment issues, particularly those that affect the up-scaling of CSLF projects to commercial scale. It should inform governments, as the CSLF is the only government-level organization, as opposed to IEA and GCCSI, and recognise the differing circumstances and therefore pace of adoption between the developed and developing country members of the CSLF. Also, the CSLF TRM should focus on cross-cutting and overarching issues rather than on details of a range of specific technologies: integration of technologies in the CCUS value chain is essential.

CSLF has established several task forces to work on important issues. Task Force 1 deals with closing technology gaps. This task force will work in parallel to the TRM. It is important that ideas and technological trends surfaced by Task Force 1 are fed into and considered in the TRM.

### Scope

The scope for the TRM is described in the following.

1. Objectives and Scope of TRM (½-¾ page)

The TRM should focus on the technology needs to enable large scale implementation of CCUS. Therefore, the needs must be identified. The objectives of the TRM should be to give answers to three simple questions, with focus on the third:

- a. What is the current status of CCUS technology and deployment today, particularly in the CSLF countries?
- b. Where should CCUS be by 2030?
- c. What is needed to get from point a) to point b), while at the same time addressing the different circumstances of developed and developing countries?

The TRM should cover CCUS in the power and industrial sectors, and CCS biomass (for negative CO<sub>2</sub> emissions) and any other major industrial CO<sub>2</sub> sources. Utilization in the early deployment stages, particularly in enhanced oil recovery, should be considered.

One objective of the TRM will be to guide governments in prioritizing technology activities in implementation of CCUS. Financial issues and cost for implementation on a scale to meet, e.g. the IEA BLUE Map scenario, are outside the scope of the CSLF TRM.

## 2. Vision and Target (½-¾ page)

Question b) above is about vision and targets. CSLF has not explicitly stated a vision or specific technology targets, but it has a Charter and Terms of Reference. These may be used to formulate agreed visions; alternatively, one can use, e.g., visions and goals from IEA (IEA BLUE Map scenario or the 2D scenario of Energy Technology Perspectives 2012) or G20, e.g., in terms of percentages or absolute numbers of emission reductions that should be achieved by CCUS by 2030, or in terms of number of large integrated projects (IEA BLUE Map scenario). The latter is the simplest and fastest solution.

## 3. Assessment of present situation (2 pages)

Brief review of present situation for large-scale integrated projects (very brief summary of GCCSI report; more could be added in appendix). Focus should be on what is needed to overcome technological barriers to fully commercial implementation, as opposed to policy or financial barriers:

- Technology barriers such as integration, industrial applications and infrastructure. Details of specific technologies have been dealt with in several earlier TRM's. This TRM should mainly use references and appendices.
- Engagement from and fear amongst public related to safe storage and other HSE aspects
- Need to establish baseline parameters and monitoring to evaluate the fate of the injected CO<sub>2</sub>, particularly to address regulatory requirements and allay public concerns
- Incomplete implementation or lack of laws and regulations
- Lack of market pull, insufficient funding mechanisms (only as background, outside the scope of the TRM).
- Balancing of diverse interests – e.g. balancing the need to reduce GHG emissions with other environmental and public concerns, and economic development with environmental protection in developing countries.

4. Prioritized technology related RD&D activities (5 pages + graphs).

The updated TRM should focus on technological aspects that can contribute to elimination of technology barriers to large scale implementation of CCUS.

Examples are:

- Consistent methods for evaluating storage capacity (as opposed to storage resources) and global distribution of this capacity (important for policy makers);
- Application in the power generation sector (so far there is no large-scale demo project in this sector; only in the oil and gas sector)
- Industrial applications, where, again, no large-scale projects are being planned;
- Integration of CCUS in power systems retaining flexibility (should include retrofitting); CO<sub>2</sub> transportation infrastructure.
- Large scale storage demonstration projects to prove that monitoring works and that leaks can be prevented or detected;
- Remediation of or contingencies for leaks;
- Environmental, safety and health aspects along whole CCUS chain in a life cycle perspective.

Much can be said in graphical form. Examples of roadmap graphs are shown below.

5. Recommendations for Implementation; Actions (1-1½ pages + graphs)

This section should focus on recommendations for technology implementation, the necessary policy framework will be assumed in place.

6. Follow-up Plans (½-1 page)

- How to monitor progress
- Plans for updates

7. Appendices according to agreement, e.g.:

- Implementation status – large integrated projects
- Closing the technology gaps - more detailed technology status and needs
- Regulations
- A view to 2050 - what 3<sup>rd</sup> generation technologies do we need to be piloting in the 2020s getting ready for deployment beyond 2030

## The Process

The process to develop the CSLF TRM 2013 may be divided into the following phases and tasks:

Task 1: Agreement by the Steering Committee on this Discussion Document, and Scope and Table of Contents of the TRM.

This should include:

- a. Agreement on the scope and boundaries of the TRM (Chapter 1)
- b. Agreement on vision and targets (Chapter 2)

Task 2: Identification of means or ways to produce the TRM.

This task also includes allocation of resources necessary to perform the work with the TRM. These two tasks should be achieved prior to the CSLF meeting in Perth on October 24-26, 2012.

**Task 3: Development of TRM.**

This phase could include the following activities:

- a. Prepare status and assessment (Chapter 3)
- b. Prepare prioritized technology related RD&D activities (Chapter 4). This should be the responsibility of the SC (closing the gaps task force will feed into this process).
  - i. Identify and specify areas that will be the focus of the TRM
  - ii. Specify the drivers for the areas and the area targets
  - iii. Identify and recommend technology alternatives to be pursued, with time lines.
- c. Prepare recommendations for implementation (Chapter 5)
- d. Prepare follow-up plan (Chapter 6)
- e. Prepare draft report

In parallel to the above the closing the gaps task force will be prepared and will surface ideas and technological trends that could be considered in the road map.

**Task 4: Approval.**

This phase could include the following activities:

- a. Consultation round with critique, comments and validation by CSLF TG members
- b. Revision
- c. Submission and Approval at Ministerial meeting fall 2013.

Suggested timeline:

Phase	Task/Activity	2012					2013										
		Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1	Boundaries and scope		→														
	Visions and targets		→														
2	Means to produce TRM		→														
3	Status and assessment				→												
	Prepare prioritized RD&D activities				→												
	Recommendations for implementation								→								
	Follow-up plans								→								
	Draft report								→								
4	Hearing, comments												→				
	Revision													→			
	Final report															✘	

## List of Contents

Each of the numbered headlines below is intended to represent a chapter in the TRM.

1. Executive Summary (why, what, how)
2. Recommendations
3. Objectives and Scope of TRM (½-¾ page)
4. Vision and Target (½-¾ page)
5. Assessment of present situation (2 pages)
6. Prioritized technology related RD&D activities (5 pages + graphs)
7. Summary and Follow-up plans (1-2 pages)
8. Appendices

Note: In the final report it is suggested to have the Recommendations appear up front for the Ministers to see them without having to read the full document, whereas they are among the last topics to be worked out. Thus the order in the proposed list of content is different from the order in the scope.

### Organization:

The SC should take a more active role than just deciding on the content and supervising the work. This applies in particular to the suggested Tasks 1b (Chapter 2) and 3b (Chapter 4). One approach could be to have SC members submit written contributions to the identified areas in Tasks 3b, 3c and 3d and have one SC member function as editor and prepare the more straight forward parts of the TRM.



## **TECHNICAL GROUP**

### **Update on CSLF Technical Group Action Plan**

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## CSLF IS GOING GREEN\*

### UPDATE ON CSLF TECHNOLOGY GROUP ACTION PLAN

*Note by the Secretariat*

#### Background

At the 4<sup>th</sup> CSLF Ministerial Meeting, at Beijing, China in September 2011, the Technical Group approved a new multi-year Action Plan to identify priorities and provide a structure and framework for conducting Technical Group efforts through 2016. This paper provides an update of Action Plan activities to date and provides a listing of all 12 Action Plan Items.

#### Action Requested

The Technical Group is requested to review the updated Summary and Action Plan.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.

# **Update on the Technical Group Action Plan**

At the Beijing Meeting, the Technical Group set forth a strategic outlook and adopted a Five-Year Action Plan, in which 12 Action Items were listed. (Copy attached) At the direction of the CSLF Technical Group the Secretariat conducted a survey to identify the priorities of the Technical Group Delegates. The results of the survey were reported at the PIRT and Technical Group Meetings held in Bergen Norway in June 2012.

To date, 4 Task Forces have been formed to identify the activity regarding the status and to identify a technology path forward for Action Plan Items. The 4 Task Forces established are:

- A Task Force chaired by Canada has been formed entitled “Technical Challenges for Conversion of CO<sub>2</sub> EOR to CCS” (Action Plan Item # 7)
- A Task Force chaired by the United States has been formed entitled “CO<sub>2</sub> Utilization Options” (Action Plan Item # 12)
- A Task Force chaired by Norway has been formed entitled “Monitoring Geologic Storage for Commercial Projects” (Action Plan Item # 6)
- A Task Force chaired by Australia has been formed entitled “Technology Gaps Closure” (Action Plan Item #1)

On several items such as “Competition of CCS with Other Resources”, the Technical Group at the Bergen meeting deferred action to wait to see the forthcoming report from a similar IEA GHG study before considering a new task force on this topic.

# CSLF Technical Group Action Plan, 2011-2016

## **Action Plan 1: Technology Gaps Closure**

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

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

## **Action Plan 2: Best-Practice Knowledge Sharing**

**Action:** The Technical Group will facilitate the sharing of knowledge, information, and lessons learned from CSLF-recognized projects and other CCS RD&D. (*note: This activity could also be linked with the Capacity Building Task Force.*)

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

## **Action Plan 3: Energy Penalty Reduction**

**Action:** The Technical Group will identify technological progress and any new research needs for reducing the energy penalty for CCS, both for traditional CO<sub>2</sub> capture processes and new breakthrough technologies.

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

## **Action Plan 4: CCS with Industrial Emissions Sources**

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

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

## **Action Plan 5: CO<sub>2</sub> Compression and Transport**

**Action:** The Technical Group will review technologies and assess pipeline standards for CO<sub>2</sub> transport, in particular in relation to impurities in the CO<sub>2</sub> stream. Issues such as thermodynamics, fluid dynamics, and materials of construction, will be considered. Alternatives to pipelines, such as ship transport, will also be assessed.

**Outcome:** Identification of optimum technical CO<sub>2</sub> transport strategies, both for pipeline and non-pipeline alternatives. Assessment of purity issues as they apply to CO<sub>2</sub> transport. Identification of optimal compression options and alternatives.

### **Action Plan 6: Storage and Monitoring for Commercial Projects**

**Action:** The Technical Group will identify and review standards for CO<sub>2</sub> storage and monitoring.

**Outcome:** Identification of standards for storage and monitoring of injected CO<sub>2</sub>. The application of such standards should inform CO<sub>2</sub> crediting mechanisms.

### **Action Plan 7: Technical Challenges for Conversion of CO<sub>2</sub> EOR to CCS**

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

**Outcome:** Identification of permitting, monitoring, and reporting requirements for CO<sub>2</sub> EOR applications that apply for CO<sub>2</sub> credits.

### **Action Plan 8: Competition of CCS with Other Resources**

**Action:** The Technical Group will examine criteria for assessing competing development priorities between CCS (particularly CO<sub>2</sub> storage) and other economic resources. (*note: This could be undertaken as a Joint Policy and Technical Group activity.*)

**Outcome:** Identification of criteria for determining relative economic viability of CO<sub>2</sub> storage sites.

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

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

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

### **Action Plan 10: Risk and Liability**

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

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

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

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

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

### **Action Plan 12: CO<sub>2</sub> Utilization Options**

**Action:** The Technical Group will investigate CO<sub>2</sub> utilization options.

**Outcome:** Identification of most economically attractive CO<sub>2</sub> utilization options.



## **TECHNICAL GROUP**

### **CO<sub>2</sub> Utilization Options Task Force Phase 1 Report**

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## CSLF IS GOING GREEN\*

### CO<sub>2</sub> UTILIZATION OPTIONS TASK FORCE PHASE 1 REPORT

*Note by the Secretariat*

#### Background

At the 4<sup>th</sup> CSLF Ministerial Meeting, at Beijing, China in September 2011, the Technical Group approved a new multi-year Action Plan. “CO<sub>2</sub> Utilization Options” is one of the twelve Actions that comprise the Action Plan, and the United States is leading a new Task Force that will focus on CO<sub>2</sub> utilization options that have the potential to yield a significant, net reduction of CO<sub>2</sub> emissions in sufficient volumes to make a meaningful contribution to global warming and climate change objectives. This document is the Task Force’s Phase 1 Report, which provides a summary of current knowledge of the use and re-use of CO<sub>2</sub>.

#### Action Requested

The Technical Group is requested to review the Task Force’s Phase 1 report.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.

# **CO<sub>2</sub> Utilization Options - Phase 1 Report**

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**Draft Version**

August 23, 2012

**Prepared for Carbon Sequestration Leadership Forum**

**CO<sub>2</sub> Utilization Options Task Force**

# CO<sub>2</sub> Utilization Options - Phase 1 Report

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## List of Acronyms and Abbreviations

Acronym/Abbreviation	Definition
AMSO	American Shale Oil
ANL	Argonne National Laboratory
ANS	Alaska North Slope
ARI	Advanced Resources International
ARRA	American Recovery and Reinvestment Act
ASTM	American Society for Testing and Materials
bbl	Barrel (of crude oil, 42 U.S. gallons)
bbl eq	Barrel equivalent
BD	Biodiesel (fatty acid alkyl esters)
BOE	Barrels of oil equivalent
CaCO <sub>3</sub>	Calcite
CaMg(CO <sub>3</sub> ) <sub>2</sub>	Dolomite
CBM	Coalbed Methane
CCS	Carbon Capture and Storage
CF	Critical Fluid
CH <sub>4</sub>	Methane
CMAP	Carbonate Mineralization by Aqueous Precipitation (Calera)
CO <sub>2</sub> CRC	Cooperative Research Centre for Greenhouse Gas Technologies
COE	Cost of Electricity
CO <sub>2</sub>	Carbon Dioxide
CO <sub>2</sub> -EOR	Carbon Dioxide-Enhanced Oil Recovery
CSLF	Carbon Sequestration Leadership Forum
DOE	U.S. Department of Energy
ECBM	Enhanced Coalbed Methane
EGR	Enhanced Gas Recovery
EGHR	Enhanced Gas Hydrate Recovery
EOR	Enhanced Oil Recovery
EPA	U.S. Environmental Protection Agency
EtOH	Ethanol
FAME	Fatty Acid Methyl Esters
gal	gallon (unit of volume, 3.8 liters)
GGBFS	Ground Granulated Blast Furnace Slag
GHG	Greenhouse Gas
GT	Giga tonne (1 billion metric tonnes)
H <sub>2</sub> O	Water
H <sub>2</sub> S	Hydrogen Sulfide

*Draft*

<b>Acronym/Abbreviation</b>	<b>Definition</b>
HCPV	Hydrocarbon Pore Volume
HRBP	HR BioPetroleum
HTGR	Very High Temperature Gas Reactor
IABR	Integrated Algal Biorefinery
IEA	International Energy Agency
IEA GHG	IEA Greenhouse Gas R&D Programme
IGCC	Integrated Gasification Combined Cycle
INL	Idaho National Laboratory
KCl	Potassium chloride
KGS	Kentucky Geological Survey
LICADO	Liquid Carbon Dioxide (Process)
LLNL	Lawrence Livermore National Laboratory
MCF	Thousand cubic feet (10 <sup>3</sup> ft <sup>3</sup> )
MDS	Marine Desalination Systems, LLC
MgCO <sub>3</sub>	Magnesium Carbonate
MIT	Massachusetts Institute of Technology
MT	Million Metric Tonnes
MTPA	Million Metric Tonnes per Annum
MW	Mega Watt
N <sub>2</sub>	Nitrogen
NA	(Data) Not Available
Na <sub>2</sub> CO <sub>3</sub>	Sodium Carbonate (soda ash, washing soda)
NaHCO <sub>3</sub>	Sodium Bicarbonate (baking soda)
NEA	Nuclear Energy Agency
NETL	U.S. DOE National Energy Technology Laboratory
NO <sub>2</sub>	Nitrogen Dioxide
NO <sub>x</sub>	Nitrogen Oxides (NO, NO <sub>2</sub> )
O <sub>2</sub>	Oxygen
ORNL	Oak Ridge National Laboratory
PBR	Photobioreactor
PC	Propylene Carbonate
PPC	Polypropylene Carbonate
RCSP	U.S. DOE Regional Carbon Sequestration Partnership
RF	Radio Frequency
RFS2	revisions to the National Renewable Fuel Standard
SCF	Standard Cubic Feet
SCM	Supplementary Cementitious Material
SFE	Supercritical Fluid Extraction

*Draft*

<b>Acronym/Abbreviation</b>	<b>Definition</b>
SOTA	State of the art
SO <sub>x</sub>	Sulfur oxides (sulfur dioxide, sulfur trioxide)
TAG	Triacyl glycerol
TBD	To Be Determined
TCF	Trillion cubic feet (10 <sup>12</sup> ft <sup>3</sup> )
TPD	Metric tonnes per day
UIC	Underground Injection Control (Program)
VES	Viscoelastic Surfactant

## Definitions

1. **Beneficial use:** A process, technology, or application which generates valuable chemicals, fuels, raw materials, or has considerable environmental or economic advantages over the status quo.
2. **Hydrocarbon resource recovery applications:** Applications where CO<sub>2</sub> is used to enhance the production of hydrocarbon resources.
3. **Re-use (non-consumptive) applications:** Applications where CO<sub>2</sub> is not consumed directly, but re-used or used only once while generating some additional benefit (compared to sequestering the CO<sub>2</sub> stream following its separation).
4. **Consumptive applications:** These applications involve the formation of minerals, or long-lived compounds from CO<sub>2</sub> which results in carbon sequestration by '*locking-up*' carbon.
5. **Nominal-net benefit:** The value realized from the use of CO<sub>2</sub> less the costs of raw materials involved in the CO<sub>2</sub>-use process. This approach does not account directly for the capital costs of CO<sub>2</sub> utilization, which are process-specific. The costs of CO<sub>2</sub> capture and compression are aggregated as the cost of high-pressure, pure CO<sub>2</sub> (assumed to be 40 \$/T). Relative comparisons of net benefits from various beneficial uses are more relevant than the absolute values themselves.
6. **Direct benefit:** A beneficial use which, by itself, leads to the reduction of CO<sub>2</sub> emissions over a given time period, without considering other related processes.
7. **Indirect benefit:** A beneficial use which, by itself does not reduce CO<sub>2</sub> emissions, but mitigates CO<sub>2</sub> when considered in conjunction with several related processes, as a part of a particular lifecycle, or a system-wide analysis.
8. **Indirect CO<sub>2</sub> emissions:** CO<sub>2</sub> emitted during a CO<sub>2</sub>-use process, as a result of energy consumption in the application, or arising as CO<sub>2</sub> emissions from energy expended in forming or processing the raw materials used in the application.
9. **Cost of CO<sub>2</sub> reduction:** Nominal net cost (or benefit). If it is less than zero, it is the nominal net-positive benefit.
10. **Indirect-carbon avoidance:** CO<sub>2</sub> emissions avoided as a result of the indirect-application, or use of CO<sub>2</sub>. Typical examples include reduction in CO<sub>2</sub> emissions from gains in process efficiency, single- or multiple-reuse or recycling of CO<sub>2</sub> which displaces the use of fossil fuel-derived energy in a particular application or process.

## Executive Summary

This document provides a summary of current knowledge of the use and re-use of carbon dioxide (CO<sub>2</sub>). Simply put, use or reuse options provide a value to the end-user which creates a market for CO<sub>2</sub> producers. The use of CO<sub>2</sub> in various applications may have economic and/or environmental benefits. Historically, the market for the use of CO<sub>2</sub> has been relatively small compared to anthropogenic CO<sub>2</sub> emissions. However, there is an impetus to explore additional uses and benefits of CO<sub>2</sub> to mitigate CO<sub>2</sub> emissions. All processes discussed here provide incremental advantages resulting from using CO<sub>2</sub>, when compared to present day consumption. No single process will mitigate all anthropogenic CO<sub>2</sub>. However, with continued support of research and development, the number of applications is increasing. In combination with geologic sequestration these applications could lead to significant benefits.

The metrics utilized in this summary considered the following:

- Total amount of CO<sub>2</sub> permanently sequestered
- Unit value (benefit) or cost of application
- Energy consumed by the application (or net-CO<sub>2</sub> savings from the technology)
- Market Potential of primary CO<sub>2</sub> use and any by-products

These considerations were used to establish more detailed metrics to compare each of the various technologies. This summary provides more detailed discussion on the technologies found and provides summary tables for the various categories.

Various CO<sub>2</sub> use applications were classified into three categories: resource recovery, non-consumptive uses, and consumptive uses. To make a meaningful impact, a CO<sub>2</sub> use process should use large quantities of CO<sub>2</sub>, or result in a large net-benefit, or preferably both.

Resource recovery applications include the use of CO<sub>2</sub> for enhanced oil recovery (EOR), enhanced gas recovery (EGR), fracturing, enhanced coalbed methane production (ECBM), and oil shale recovery. Among the resource recovery applications, CO<sub>2</sub>-EOR has a significant potential to mitigate CO<sub>2</sub> (16-22 billion T CO<sub>2</sub> by 2050) with a relatively high-net benefit (~\$100 /T CO<sub>2</sub> economic margin, 167 to 243 \$/T net-benefit). This analysis assumed an oil price of \$85/bbl and CO<sub>2</sub> price of \$40/T. The use of CO<sub>2</sub> to recover natural gas from depleted gas reservoirs, CO<sub>2</sub>-enhanced gas recovery (CO<sub>2</sub>-EGR) has the technical potential to use up to 3,200 to 7,800 MT CO<sub>2</sub>/y till 2050 (or 160 to 390 giga tons of CO<sub>2</sub>). The technical, U.S. potential for CO<sub>2</sub> use in enhanced-coalbed methane (CO<sub>2</sub>-ECBM) production over 50 years is about 60 to 117 GT CO<sub>2</sub> (1,200 to 2,340 MT CO<sub>2</sub>/y). Up to 2.2 MCF of natural gas could be produced for every metric tonne of CO<sub>2</sub> stored. Assuming a nominal natural gas price of \$2/MCF, the nominal-net benefit would be approximately \$4.4/T CO<sub>2</sub>. About 0.4 T of CO<sub>2</sub> could be used per vertical-well completion, if employed as a fracturing agent. Approximately 18 MT CO<sub>2</sub>/y would be required for a facility to produce 1 million bbl/d of syncrude from in situ processing of oil shale. CO<sub>2</sub>-EGHR and use for oil shale recovery are also beneficial, but the amount of CO<sub>2</sub> which could potentially be used in these applications is relatively uncertain. The benefits from resource recovery could partly offset the costs of carbon capture. Unlike CO<sub>2</sub>-EOR which is relatively more mature, oil recovery from oil shale using CO<sub>2</sub>, CO<sub>2</sub> fracturing, CO<sub>2</sub>-EGR, CO<sub>2</sub>-ECBM, and CO<sub>2</sub>-EGHR are processes still being developed or tested in pilot-scale tests.

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Non-consumptive CO<sub>2</sub>-use applications have an indirect-CO<sub>2</sub> reduction benefit in the form of production of fresh water or valuable minerals, higher efficiency, or the displacement of fossil fuels. Seven non-consumptive uses were discussed in the report: desalination, beneficiation, slurry transport, heat transfer fluid, freight pipelines, solvent extraction, and the conversion of CO<sub>2</sub> to fuels and chemicals. Of these, 'closed-loop' re-use applications where CO<sub>2</sub> is used to produce minerals, or higher process efficiency may have limited potential demand for CO<sub>2</sub>. Income from the sale of fresh water may offset some of the cost of CO<sub>2</sub> capture. The use of CO<sub>2</sub> for supercritical fluid extraction is a commercial-scale process. The rest of the non-consumptive, 'closed-loop' re-use applications are relatively less-technologically mature, and require research and development.

Nominal-net benefit analysis indicates that the conversion of CO<sub>2</sub> to fuels such as diesel, gasoline and methanol (approximately -200 \$/T) is less 'beneficial' than CO<sub>2</sub> to chemicals (formic acid, acrylic acid, plastics: approximately 750 to 2,000 \$/T). However, the potential CO<sub>2</sub> demand for producing chemicals is small (~millions of tonnes per year overall) compared to amount of CO<sub>2</sub> demand from its conversion to fuels (billions of tonnes per year). Both of these applications recycle carbon from fossil fuels. It is to be noted that the production of urea and certain other chemicals from CO<sub>2</sub> is occurring on a commercial-scale. However, the conversion of CO<sub>2</sub> to fuels requires large-scale demonstrations, and the integration of multiple proven steps (e.g., methanol-to-gasoline process, CO<sub>2</sub> conversion to methanol). Similarly the conversion of CO<sub>2</sub> to high-value chemicals also requires pilot-scale testing and development.

Various consumptive uses, or applications where CO<sub>2</sub> is converted into products with a long-life, form the basis for the third category of CO<sub>2</sub> uses. Several processes currently being developed to convert CO<sub>2</sub> to sodium or calcium/magnesium carbonates/bicarbonates were evaluated. In general, consumptive uses may have the potential to use or mitigate large quantities (billions of tonnes per year globally) of CO<sub>2</sub>. However, larger scale demonstration pilots are needed to evaluate their feasibility. In addition to mineral carbonates, other by-products from consumptive-use processes include chlorine, hydrogen, soil amendments, fertilizers, and building materials. Nominal-net benefits from consumptive uses vary from \$10 to \$300/T CO<sub>2</sub> depending on the product.

The table on the following page provides a summary of various applications which are further discussed in various sections of the document.

		<b>CO<sub>2</sub> considered permanently sequestered, (global, MT CO<sub>2</sub>/yr)</b>	<b>Benefit</b>	<b>Impact (nominal-net benefit, \$/T CO<sub>2</sub>)<sup>1</sup></b>
<b>Resource Recovery</b>	<b>CO<sub>2</sub>-EOR (mainly miscible)</b>	320 to 446 <sup>2*</sup> , Net: 246 to 343*	Crude oil	Gross impact: 167 to 243*
	<b>CO<sub>2</sub>-EGR</b>	3,200 to 7,800 <sup>3</sup>	Natural gas	NA
	<b>CO<sub>2</sub> Fracturing</b>	NA	Natural gas	NA
	<b>CO<sub>2</sub>-ECBM</b>	1,200 to 2,340 <sup>4</sup>	Natural gas	NA
	<b>CO<sub>2</sub>-Enhanced Gas Hydrate Recovery</b>	NA	Natural gas	NA
	<b>Oil Shale Recovery</b>	NA	Hydrocarbons/syncrude	Less than CO <sub>2</sub> -EOR
<b>Non-Consumptive Uses</b>	<b>Desalination</b>	Indirect	Fresh water	NA
	<b>Beneficiation</b>	Indirect	Minerals such as rare earths	NA
	<b>Feed solids to gasifiers or for slurry transport</b>	Indirect	Increased efficiency	NA
	<b>Heat transfer fluid</b>	Indirect	Increased efficiency	NA
	<b>Freight pipelines</b>	Indirect	Increased efficiency	NA
	<b>Solvent Extraction</b>	Indirect	Increased efficiency	NA
	<b>Fuels and chemicals</b>	Indirect	Displaces fossil fuels	2,000* to -200*
<b>Consumptive Uses (carbonation)</b>	<b>Skyonic</b>	20 to 4,842 <sup>5</sup>	Sodium carbonate, bicarbonate	10* to 300*
	<b>Alcoa</b>	2.6 to 23*	Soil amendment, fertilizer	10* to 300*
	<b>Calera</b>	12 to 1,500*	Aggregate, supplementary cementitious material (SCM)	14* to 100*
	<b>Concrete Carbonation</b>	1.8 to 8*	Precast concrete	NA
	<b>Slag Carbonation</b>	6.5 to 18*	Soil amendment	NA
	<b>Novacem</b>	54*/ 2,130	SCM	NA
	<b>Cambridge Carbon Capture</b>	Similar in scale to Novacem & Calera	Carbonate building materials	NA

\* indicate U.S.-specific estimates or values.

In the development of this summary some conclusions became apparent:

1. No single application is capable of consuming major fractions of current or projected CO<sub>2</sub> emissions. However, large potential beneficial impacts (\$/T CO<sub>2</sub>eq) could be realized over the next few decades.

<sup>1</sup> The net-positive benefit is explained in the 'Definitions' section.

<sup>2</sup> Economic margin: 100 \$/T, time period: 30 years, from ARI analyses, economic margin of CO<sub>2</sub>-EOR is \$15 to \$25/bbl.

<sup>3</sup> Time period: 50 years. 160 to 390 GT CO<sub>2</sub> globally can be sequestered via CO<sub>2</sub>-EGR (technical storage capacity)

<sup>4</sup> Time period: 50 years. 60 to 117 GT CO<sub>2</sub> can be stored in unmineable coalbeds in North America (technical storage capacity).

<sup>5</sup> 100% market share, or total available markets

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2. Currently hydrocarbon resource recovery holds the greatest potential for CO<sub>2</sub> use, in terms of amount of CO<sub>2</sub> used annually. Generally, these applications are better understood and closest to practical application at a large scale.
3. Using CO<sub>2</sub> to produce fuels is also a potentially high capacity re-use of CO<sub>2</sub> if there was a high-market penetration, but is limited by the cost of hydrogen, or the relatively-high cost of producing fuels from photosynthetic microorganisms. Producing chemicals is a less costly re-use but the amount of CO<sub>2</sub> used is considerably lower than the CO<sub>2</sub>-to-fuels applications.
4. Other consumptive uses hold potential to provide a sustainable sink for carbon but the market size for these applications is far more limited, based on current markets, than resource recovery options and important aspects of the various relevant process chemistries need to be proven at scale.
5. Carbonation approaches which produce building materials or aggregates, still need to be demonstrated at a scale sufficient to prove their commercial viability.
6. A number of other uses for carbon dioxide might offer indirect benefits through improved energy efficiency, through production of potable water from produced, saline waters, or simply by raising the efficiency of power cycles. These applications could improve overall efficiency from a system point of view.

It is essential to apply sound analytic methodologies to assess both the potential for use of any concept and to estimate the full range of benefits, in terms of the net carbon dioxide removed from the atmosphere, the duration of such storage (if it is not consumed), the potential market value of a use, and finally, the net energetic impact. In the metrics tables in the body of the document, we refer to the need to apply sound life cycle assessment methodologies to appreciate the benefits of many of the candidate beneficial uses.

The beneficial uses of CO<sub>2</sub> are worthy of continued research, development and demonstration. Proper incentives will lead to commercial, large-scale applications. CO<sub>2</sub> use or re-use technologies which are current and being developed are summarized in this paper.

## **1 Introduction and Scope**

This report has been developed to provide a summary of currently known uses and re-use applications for carbon dioxide (CO<sub>2</sub>). A beneficial use of CO<sub>2</sub> is a process, an operation, or a function which adds value by creating a salable product, or by improving process efficiency. The quantities of CO<sub>2</sub> used in some beneficial use applications may be small compared to the potential for CO<sub>2</sub> mitigation from geologic carbon capture and storage (CCS). However, beneficial use processes offer the benefits of value-addition (e.g., hydrocarbon resource recovery) and lower-risk perceptions (e.g., applications where carbon dioxide is consumed). Furthermore, geologic storage of CO<sub>2</sub> may not be suitable in all geographic locations, and requires the presence of suitable seals, access to pore space, and optimal permeability and porosity in the subsurface. Income from high-value products produced from the beneficial use of a slipstream of captured CO<sub>2</sub> could offset a portion of the capital and operating costs for CCS. The higher-value potential and lower-risk perception may also accelerate the development of CO<sub>2</sub> pipeline networks and the deployment of novel technologies, in turn, enhancing prospects for geologic CO<sub>2</sub> storage. For instance, CO<sub>2</sub> used for enhanced oil recovery may also be injected into suitable saline formations adjacent to the oil reservoir, thereby reducing the need for additional infrastructure (wells, pipelines, equipment) at such locations. In other cases, if the produced CO<sub>2</sub> would be used within an industrial complex, only small modifications to existing pipeline networks may be needed.

No single beneficial use technology solution would fully mitigate global CO<sub>2</sub> emissions. However, if a holistic approach is taken, and all options are considered, the sum of the applications could have a significant beneficial impact.

Further, there might be enhanced opportunities to apply these beneficial uses globally, and therefore developing such beneficial use applications may lead to competitive advantage in the short term. Low-carbon intensity products may enjoy an advantage in global trade under policies that limit GHG emissions. Therefore, developing reuse options to lower carbon intensity could lead to a competitive advantage in international trade.

The objectives of this assessment were:

- To conduct a literature survey and research previous studies on the beneficial uses or re-use of CO<sub>2</sub>
- To evaluate and quantify current and potential future beneficial uses of CO<sub>2</sub>
- To develop metrics to be used to evaluate beneficial use concepts

## **2 Overview**

This summary is designed to document processes that use and re-use of CO<sub>2</sub> and to present this information in a format that can be used as a reference tool. There are numerous applications where CO<sub>2</sub> could be used in existing or future industrial processes. Compared to the re-use options, hydrocarbon resource recovery applications have the potential to use larger quantities of CO<sub>2</sub>. Furthermore, some hydrocarbon resource recovery applications have the potential to sequester CO<sub>2</sub> in geologic formations during, or at the end of the resource recovery.

The technologies discussed in the hydrocarbon resource recovery with CO<sub>2</sub> section (Table 2) are:

1. CO<sub>2</sub>-enhanced oil recovery (CO<sub>2</sub>-EOR) and,
2. Recovery of unconventional hydrocarbons (gas, gas hydrate, oil shale, coal bed methane) with CO<sub>2</sub>
3. Improved recovery of hydrocarbons with CO<sub>2</sub> fracturing of reservoirs

The technologies discussed in the re-use section are:

1. CO<sub>2</sub>-clathrate based desalination process (Table 6),
2. Use of CO<sub>2</sub> as a working fluid (heat transfer fluid, freight pipelines, beneficiation, solvent extraction and as a medium for gasifier solid feed transport) (Table 6)
3. Production of fuels and chemicals from CO<sub>2</sub> (Table 7)<sup>6</sup>.

We note that some applications may be classified under several categories. For example, the use of CO<sub>2</sub> for geothermal energy recovery, may be considered as a resource recovery application and also as an application where CO<sub>2</sub> is re-used as a working fluid. In contrast to CO<sub>2</sub>-reuse applications, where CO<sub>2</sub> may be recycled or reused, the consumptive use applications involve the formation of minerals which contribute directly to carbon sequestration by ‘locking-up’ carbon. Various means to form mineral carbonates from CO<sub>2</sub> are discussed in the ‘consumptive use’ section. Applications described in Table 8 include Skyonic, Alcoa, Calera, Novacem, concrete carbonation and slag carbonation processes. Finally, a complete bibliography of source documents is provided.

### 3 Metrics Overview

Comparison of the various applications for CO<sub>2</sub> recovery, and their relative costs and benefits helps to identify challenges and opportunities for the increased use of CO<sub>2</sub>. An objective of this task was to develop a list of metrics to evaluate various beneficial use concepts. Performing a comparative or quantitative ranking of these options is a challenge. CO<sub>2</sub>-use technologies in this document are at varying levels of readiness and not all of the processes can be ranked against all the criteria. That stated, the primary criteria for the relative comparison of various CO<sub>2</sub> applications include:

- Total amount of CO<sub>2</sub> permanently sequestered
- Unit value (benefit) or cost of application
- Energy consumed by the application, or net-energy saved by implementing this technology ( net-CO<sub>2</sub> savings from the technology)
- Market potential of primary CO<sub>2</sub> use and any by-products

The costs of CO<sub>2</sub> separation, compression, and delivery may be accounted in various ways, depending on the allocation of the CO<sub>2</sub> allowances/credits. In this Summary, the use of CO<sub>2</sub> is treated as a cost to the operator of the CO<sub>2</sub>-use process and a benefit to the seller of the CO<sub>2</sub> offsets, possibly a CO<sub>2</sub> capture project developer. High-pressure, high-purity CO<sub>2</sub> is assumed to have a cost of 40 \$/T (consistent with NETL/ESPA [2011] analyses). We do not directly account for the cost of purifying, cooling, and compressing the flue gas in applications where it is used without CO<sub>2</sub> separation (ex: Calera, Skyonic). The nominal benefit is estimated as the value derived from the use of CO<sub>2</sub> less the costs of raw material inputs to the process<sup>7</sup>. We note that this

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<sup>6</sup> The production of organic polymers from CO<sub>2</sub> is classified as a re-use, but could also be considered as a consumptive use depending on the lifetime of the polymer. For example, organic carbonates and polyurethanes have decades-to-centuries lifetimes (see Styring et al., 2011, Carbon Capture and Utilisation in the Green Economy, Centre for Low Carbon Futures, Report 501) . For simplicity, all CO<sub>2</sub>-to-chemical processes have been classified as *re-use applications*.

<sup>7</sup> The prices of hydrogen, and other chemical inputs are accounted for in the CO<sub>2</sub>-to-fuels/chemicals application. The price of brine or seawater is not accounted for in Calera or Skyonic processes. It is expected that they would be considerably lower than the unit cost of CO<sub>2</sub> or the unit value of the product. Similarly, the alkaline earth metal silicate raw material inputs for the Calera and Novacem processes are also not assigned a price, and this may be refined in the future.

nominal benefit is a preliminary metric, and the actual benefits and costs may be estimated by a full life cycle analysis, which is out of the scope of the current task.

Another metric of relevance to CO<sub>2</sub>-use processes is the net-CO<sub>2</sub> mitigation, closely related to the amount of energy consumed in the process. Typical examples are the use of electrical, thermal, or chemical energy in applications which convert, compress, or use CO<sub>2</sub>. The net-CO<sub>2</sub> used in the process, or mitigated per unit of process output (product) would therefore be the gross-amount of CO<sub>2</sub> used per unit of product, less the amount of CO<sub>2</sub> emitted during the process per unit of product. Because (fossil) energy use and CO<sub>2</sub> emissions are correlated, emissions from the CO<sub>2</sub>-use process can also be deduced by energy consumption, energy required for capture and/or disposal, energy penalty or energy gain, and the energy use avoided.

A primary constraint on the adoption of certain technologies which use CO<sub>2</sub> is the dearth of pipeline-quality low-cost CO<sub>2</sub> supply. In hydrocarbon resource recovery applications, the cost of CO<sub>2</sub> may be a major factor driving the economics. For example, data from the NETL/ESPA (2011) analysis indicate the cost of CO<sub>2</sub> to be 11 to 17% of the cost of the recovered crude oil. In other applications such as CO<sub>2</sub>-ECBM and CO<sub>2</sub>-EGR, the proportional cost of CO<sub>2</sub> may be even higher because natural gas trades at a lower unit energy cost (\$/MMBTU) compared to crude oil. Such constraints would incentivize higher recycling and lower unit-utilization of CO<sub>2</sub>. In applications where CO<sub>2</sub> is converted to a fuel such as gasoline or diesel using hydrogen, the cost of CO<sub>2</sub> is still a considerable percentage of the value of fuel, but is outweighed by the cost of hydrogen. Therefore, the cost and the availability of hydrogen derived from CO<sub>2</sub>-free energy sources would determine the rate of adoption of technologies where hydrogen is used as a feedstock. As discussed in the Introduction, market saturation may not be a significant factor affecting the development of first-of-a-kind applications such as the conversion of CO<sub>2</sub> to fuels, chemicals and raw materials.

The tables in each of the following sections summarize the metrics and the results of an objective evaluation. Not all applications are mature enough to provide information in each category. Table 1 lists the metrics considered when comparing the applications.

Table 1 - Metric Summary

<i>CO<sub>2</sub> Mitigation</i>	<b>Amount of CO<sub>2</sub> reduced (total : direct + indirect)</b>
	<b>Amount of Captured CO<sub>2</sub> utilized (direct reduction)</b>
	<b>Amount of CO<sub>2</sub> consumed</b>
	<b>Is capture an intrinsic part of the process?</b>
<i>Benefits</i>	<b>Cost of CO<sub>2</sub> reduction/ tonne (total system basis)</b>
	<b>Cost of CO<sub>2</sub> capture and processing</b>
	<b>Value of by-products</b>

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<i>Energy Consumption</i>	<b>Energy penalty/ gain for total system (LCA)</b>
	<b>Energy required for capture and disposal</b>
	<b>Energy penalty/ gain for byproduct process</b>
	<b>Energy use avoided (without chemical transformation of CO<sub>2</sub>)</b>
<i>Market Potential</i>	<b>Market size (potential tonnage removed from atmosphere)</b>
	<b>CO<sub>2</sub> subjected to capture and storage</b>
	<b>CO<sub>2</sub> sold to commercial markets for consumption or resource recovery</b>
	<b>Market size of by-products</b>
	<b>(Nominal Benefit (Negative cost)) x Market size</b>

## 4 Hydrocarbon Resource Recovery

### 4.1 Introduction: Hydrocarbon Resource Recovery

CO<sub>2</sub>-enhanced oil recovery (CO<sub>2</sub>-EOR), 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 increase oil/gas recovery are some of the specific applications for CO<sub>2</sub>-enhanced hydrocarbon recovery. The common characteristics of CO<sub>2</sub>-enhanced hydrocarbon recovery processes include:

- Recovery of conventional and unconventional hydrocarbon resources (oil, conventional gas, shale gas, coal bed methane, oil shale and tar sands),
- Recycling, or once-through use of CO<sub>2</sub> in conjunction with hydrocarbon recovery,
- The need for high-pressure CO<sub>2</sub> and/or appropriate surface infrastructure such as wells, compressors, and pipelines. CO<sub>2</sub> purity required for each application may vary depending on the specific application.

In addition, some hydrocarbon recovery applications may enable sequestration of CO<sub>2</sub> in the hydrocarbon formation at the end of the project lifetime. The actual mechanisms involved in enhanced hydrocarbon recovery are distinct in each case, and include stripping the light-hydrocarbon components (CO<sub>2</sub>-EOR), density/pressure drive (EGR), and more favorable thermodynamics (EGHR, ECBM). The benefits in enhanced hydrocarbon recovery applications accrue from the sale of produced hydrocarbons, suitability to certain (water-sensitive or shallow) reservoirs, and the CO<sub>2</sub> offsets (to CO<sub>2</sub> emitters) resulting from sequestration over the project lifetime.

### 4.2 Metrics: Hydrocarbon Resource Recovery

Resource recovery applications include the use of CO<sub>2</sub> for enhanced oil recovery (EOR), enhanced gas recovery (EGR), fracturing, enhanced coalbed methane production (ECBM), and oil shale recovery. Among the resource recovery applications, CO<sub>2</sub>-EOR has a significant potential to mitigate CO<sub>2</sub> (16-22 billion T CO<sub>2</sub> by 2050) with a relatively high-net benefit (~\$100 /T CO<sub>2</sub> economic margin, 167 to 243 \$/T net-benefit). This analysis assumed an oil price of \$85/bbl and CO<sub>2</sub> price of \$40/T. The use of CO<sub>2</sub> to recover natural gas from depleted gas reservoirs, CO<sub>2</sub>-enhanced gas recovery (CO<sub>2</sub>-EGR) has the technical potential to use up to 3,200 to 7,800 MT CO<sub>2</sub>/y till 2050 (or 160 to 390 giga tons of CO<sub>2</sub>). The technical, U.S. potential for CO<sub>2</sub> use in enhanced-coalbed methane (CO<sub>2</sub>-ECBM) production over 50 years is about 60 to 117 GT CO<sub>2</sub> (1,200 to 2,340 MT CO<sub>2</sub>/y). Up to 2.2 MCF of natural gas could be produced for every metric tonne of CO<sub>2</sub> stored. Assuming a nominal natural gas price of \$2/MCF, the nominal-net benefit would be approximately \$4.4/T CO<sub>2</sub>. About 0.4 T of CO<sub>2</sub> could be used per vertical-well completion, if employed as a fracturing agent. Approximately 18 MT CO<sub>2</sub>/y would be required for a facility to produce 1 million bbl/d of syncrude from in situ processing of oil shale. CO<sub>2</sub>-EGHR and use for oil shale recovery are also beneficial, but the amount of CO<sub>2</sub> which could potentially be used in these applications is relatively uncertain.

Unlike CO<sub>2</sub>-EOR which is relatively more mature, oil recovery from oil shale using CO<sub>2</sub>, CO<sub>2</sub> fracturing, CO<sub>2</sub>-EGR, CO<sub>2</sub>-ECBM, and CO<sub>2</sub>-EGHR are processes still being developed or tested in pilot-scale tests.

An overview of various applications for the recovery of crude, natural gas and syncrude using CO<sub>2</sub> is presented in Table 2. Values preceding asterisks are specific to the United States.

Table 2. Hydrocarbon Resource Recovery Applications (excluding CO<sub>2</sub>-EOR)

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	CO <sub>2</sub> Mitigation		Benefits	Energy penalty/CO <sub>2</sub> emissions	Market Potential		Overall Benefits
	(A) CO <sub>2</sub> Reduced (total)	(B) Captured CO <sub>2</sub> used	(C) Value of by-products		(D) Market size (potential tonnage removed from atmosphere)	(E) Potential for commercial sales	
CO <sub>2</sub> -EGR	NA	160 to 390 GT CO <sub>2</sub> by 2050	TBD	Could be similar to CO <sub>2</sub> -EOR <sup>8</sup>	A fraction of value in (B)	High	
CO <sub>2</sub> Fracturing	NA	~0.4 T CO <sub>2</sub> /well for vertical wells <sup>9</sup>	TBD	TBD	Determined by economics & regulations		
CO <sub>2</sub> -ECBM	Technical: 60 to 117 billion T, economic: ~30 billion T	2.2 MCF NG/T CO <sub>2</sub> <sup>10</sup>	Maximum benefit: 4.4 \$/T CO <sub>2</sub> <sup>11</sup>	TBD, gas compression	NA		U.S. (2003): 66 billion \$ total*
CO <sub>2</sub> -EGHR	TBD* <sup>12</sup>	TBD	TBD	TBD	TBD		
Oil shale, tar sands	TBD	0.05 T CO <sub>2</sub> /bbl of produced hydrocarbon	less than 167 to 243* \$/T CO <sub>2</sub> for EOR <sup>13</sup>	TBD	~18 million tons (CO <sub>2</sub> )/yr (see note to B) <sup>14</sup>	High	

<sup>8</sup> Life-cycle CO<sub>2</sub> emissions from DOE/NETL-2010/1433: 71 to 95 kg CO<sub>2</sub>e/bbl oil, using 0.23 to 0.21 T CO<sub>2</sub>/bbl oil. This is lower than the 0.3 to 0.4 T CO<sub>2</sub>/bbl oil used in the NETL/ESPA (2011) study. 0.23 to 0.31 T net-CO<sub>2</sub> stored/bbl oil, or 0.23 T CO<sub>2</sub> emitted per T CO<sub>2</sub> purchased for injection .

<sup>9</sup> Fracturing fluid volumes can reach up to 200 m<sup>3</sup> (0.4 T CO<sub>2</sub>) for vertical well completions. Horizontal shale (e.g. Marcellus shale) gas wells typically have multiple fracturing stages and may require larger quantities of CO<sub>2</sub> if it is used as a fracturing fluid.

<sup>10</sup> ARI 2003 report

<sup>11</sup> Assumes nominal natural gas price of \$2/MCF

<sup>12</sup> A fraction of the 85 TCF technically recoverable Alaskan gas hydrate resource may be produced.

<sup>13</sup> By-product hydrocarbons require upgrading compared to crude oil

<sup>14</sup> Tar sands: 1 to 5 million barrels/day (bbl/d). In-situ processing of 1 MM bbl/da would require 18 million T CO<sub>2</sub>/y

### **4.3 CO<sub>2</sub>-EOR**

Enhanced oil recovery (EOR) refers to the introduction of heat, chemicals, and/or gases to stimulate the production of oil unrecovered during primary and secondary oil production. CO<sub>2</sub>-EOR has been used extensively in mature light- and medium-oil and gas reservoirs. The CSLF EOR working group is developing a summary dedicated to CO<sub>2</sub>-EOR. The scope of this report is focused on utilization options other than EOR.

### **4.4 CO<sub>2</sub> Use for Unconventional Hydrocarbon Recovery**

The potential of using CO<sub>2</sub> for EOR has been investigated extensively. In addition to CO<sub>2</sub>-EOR, unconventional hydrocarbon recovery processes include CO<sub>2</sub> injection for enhanced gas recovery, the use of CO<sub>2</sub> as a fracturing medium for conventional gas/oil reservoirs and shale formations, the production of coal-bed methane from CO<sub>2</sub>, and the use of CO<sub>2</sub> as a transport medium and solvent for extracting hydrocarbons from oil shale and tar sands. The gas is typically recovered and re-compressed at the end of the process.

The use of CO<sub>2</sub> for unconventional hydrocarbon recovery involves a variety of considerations, some of which are distinct from those for CO<sub>2</sub>-EOR. Some of these questions are:

1. Is CO<sub>2</sub> locally available at a moderate price? Is the project economically feasible at the price of supplied CO<sub>2</sub>?
2. Is the process energy efficient, or does it consume more energy than it would produce?
3. Does the injected CO<sub>2</sub> contaminate the hydrocarbon being produced?
4. Do the impurities in CO<sub>2</sub> (such as SO<sub>x</sub>, H<sub>2</sub>S, N<sub>2</sub>) affect the product quality, and would any of these gases need to be separated from CO<sub>2</sub> before its use?
5. Would the use of CO<sub>2</sub> affect the water/resource consumption or production in the process (ECBM, extraction)?
6. Is surface infrastructure needed to separate and re-inject the produced CO<sub>2</sub> already in place?

#### 4.4.1 CO<sub>2</sub>-Enhanced Gas Recovery (CO<sub>2</sub>-EGR) and CO<sub>2</sub> Sequestration EGR (CSEGR)

Gas reservoirs suitable for CO<sub>2</sub>-EGR include both conventional (i.e. 'tight' sandstone or carbonate reservoirs) and unconventional shale-gas reservoirs. The mechanism of CH<sub>4</sub> recovery is different in both cases. In conventional reservoirs, CO<sub>2</sub> displaces the methane present in the pore space. In contrast, CO<sub>2</sub> in shale reservoirs adsorbs on the organic surfaces and desorbs methane which flows through natural and artificial fractures to the wellbore. Reservoirs containing high amounts of acid gases (CO<sub>2</sub>, H<sub>2</sub>S) may be suitable candidates for injecting CO<sub>2</sub>, especially because of existing gas separation infrastructure. Examples of CO<sub>2</sub> injection into (conventional) gas reservoirs are shown in the following table.

Table 5. CO<sub>2</sub> Injection Projects in Gas Reservoirs

Project	Features	Purpose	Injection Rate
K12-B offshore gas field, North Sea (Netherlands)	CO <sub>2</sub> separated from natural gas (13% CO <sub>2</sub> ) from a nearly-depleted gas reservoir and injected into the same sandstone formation at a depth of 4,000 m	Storage, EGR	NA
CO <sub>2</sub> CRC Otway Storage Project, Victoria, Australia	80% CO <sub>2</sub> , 20% CH <sub>4</sub> injection into a depleted gas formation underlying the active-gas producing formation) at a depth of 2,100 m	Storage	150 TPD
Altmark gas field, Germany (Vattenfall AB and Gaz de France)	Proposed CO <sub>2</sub> injection in a nearly-depleted gas field, CO <sub>2</sub> captured from oxycombustion plant	EGR	NA
In Salah, Algeria	CO <sub>2</sub> injection into a deep saline aquifer, part of the same formation and lower than ('down-dip' of) the natural gas reservoir	Storage	548 TPD/well

**Tight Gas Sandstone Reservoirs:** Compared to oil fields, gas reservoirs have higher primary recovery rates (~55-90%), and therefore, the amount of additional CH<sub>4</sub> produced may not justify the economics of CO<sub>2</sub> pressurization and injection. Rapid CO<sub>2</sub> breakthrough to the natural gas producing wells would lead to an increase in the CO<sub>2</sub> content of the produced gas, increasing separation costs and eventually making reinjection economically unfeasible<sup>15</sup>. On the other hand, injection into the gas reservoirs would indirectly pressurize the existing natural gas, thereby enhancing methane production and preventing water ingress<sup>16</sup>. CO<sub>2</sub>-EGR is economical in cases where a significant portion of the original gas in place is yet to be recovered, and where the gas reservoir has considerable vertical extent.

<sup>15</sup> CSLF, 2010. 2010 Carbon Sequestration Leadership Forum Technology Roadmap, Available at: [http://www.cslforum.org/publications/documents/CSLF\\_Technology\\_Roadmap.pdf](http://www.cslforum.org/publications/documents/CSLF_Technology_Roadmap.pdf) [Accessed November 10, 2010].

<sup>16</sup> Benson, S. et al., 2004. GEO-SEQ Best Practices Manual. Geologic Carbon Dioxide Sequestration: From Site Selection to Implementation, 9/30/2004: Lawrence Berkeley National Laboratory, Available at: <http://escholarship.org/uc/item/27k6d70j>

**Gas Shales:** Organic-rich shales (such as carbonaceous shales occurring throughout the Appalachian Basin and other parts of the world), are relatively non-porous and impermeable compared to conventional gas and tight sandstone gas reservoirs. Methane is adsorbed on clay and kerogen shale surfaces. The organic-rich shale often serves as the seal for underlying hydrocarbon formations, is a source-rock in itself, for hydrocarbons, and may also serve as a means to sequester CO<sub>2</sub>. Similar to coal beds, organic shales adsorb CO<sub>2</sub> and preferentially desorb methane. The common technique of fracturing leads to the formation of high-permeability pathways for fluid transport in the shale, resulting in enhanced CO<sub>2</sub> sequestration concomitant with methane production.

The potential for CO<sub>2</sub> storage in conventional gas reservoirs and regional organic-rich shales in the U.S. has been estimated by IEA GHG, NETL and Kentucky Geological Survey (KGS). A depleted gas fields study, using regional GIS-based source-sink matching was conducted for IEA GHG in 2008<sup>17</sup>. Capacity calculations were made with reference to the CSLF “resource pyramid” classification scheme. The IEA GHG study estimated that the available, matched, global-depleted gas field CO<sub>2</sub> storage capacity up to 2050 is 156 billion (metric) tonnes (GT) CO<sub>2</sub>. More recent IEA GHG studies indicate a global capacity of 160 to 390 GT CO<sub>2</sub><sup>18,19</sup> or enough capacity to store 30 to 70 years of U.S. energy-related CO<sub>2</sub> emissions. In the U.S.A., KGS evaluated the organic-rich shales of Kentucky to have the potential to sequester 28 billion tons of (28 GT) CO<sub>2</sub><sup>20</sup>. Similarly, a recent NETL study noted that the Marcellus Shale Formation had the potential to store 17 to 166 GT CO<sub>2</sub><sup>21</sup>. Note that some of these estimates are technical capacity estimates and do not account for the economics of natural gas production.

Estimates for CO<sub>2</sub> storage and methane production in shale reservoirs are subject to high uncertainties because they were calculated based on the adsorption isotherm data collected in the laboratory. At the reservoir scale, multiple techno-socio-economic factors, such as low-permeability, shale swelling, operator concerns about CO<sub>2</sub> diluting the produced methane, or negative public perceptions may lower this potential.

#### 4.4.2 CO<sub>2</sub>-EGR Factsheet

<b>Estimated impact /Net CO<sub>2</sub> considered permanently sequestered (US)</b>	Estimates vary from 160 to 390 GT CO <sub>2</sub> for conventional depleted gas reservoirs worldwide, and tens of GT CO <sub>2</sub> for each of the various regional shale gas plays in North America
<b>Gross current CO<sub>2</sub> consumption in this use MT/year</b>	TBD –K12-B: 0.48 MT/y, see Figure 2
<b>Game-changing events/scenarios favorable</b>	Adoption of technologies that use (impure) natural gas close to

<sup>17</sup> IEA GHG, 2009. Storage in Depleted Gas Fields, IEA GHG Technical Report, 2009/1, Available at: <http://www.ieaghg.org/index.php?/technical-reports-2009.html>

<sup>18</sup> Wildgust, N., 2009, Global CO<sub>2</sub> geological storage capacity in hydrocarbon fields, presented at IEA GHG Weyburn-Midale Monitoring Project PRISM meeting, June 2009, Regina, Canada

<sup>19</sup> Wildgust, N., 2009, Global mapping of CO<sub>2</sub> sources and sinks, presented at NACAP Workshop, 22-23 June 2009, Pittsburgh, USA

<sup>20</sup> Nutall, B. C., J. A. Drahovsal, C. Eble and R. M. Bustin, 2005, CO<sub>2</sub> Sequestration in Gas Shales of Kentucky, Search and Discovery Article #40171, Available at: [www.searchanddiscovery.net/documents/2005/nutall/index.htm](http://www.searchanddiscovery.net/documents/2005/nutall/index.htm), Accessed November 10, 2010.

<sup>21</sup> NETL, 2010. Impact of the Marcellus Shale gas play on current and future CCS activities, Available at: [http://www.netl.doe.gov/technologies/carbon\\_seq/refshelf/Marcellus\\_CCS.pdf](http://www.netl.doe.gov/technologies/carbon_seq/refshelf/Marcellus_CCS.pdf).

<p><b>for this process</b></p>	<p>the wellhead (either for electricity or chemicals), significantly increased demand for natural gas, GHG legislation</p>
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Figure 2. The K12-B offshore platform in the North Sea where CO<sub>2</sub> is injected into a sandstone formation containing natural gas. Source: [co2geonet.com](http://co2geonet.com)

<p><b>Gross/net CO<sub>2</sub> reduction per tonne of primary CO<sub>2</sub></b></p>	<p>TBD, impacts apply to both conventional depleted gas reservoirs and shale gas formations</p>
<p><b>Estimated scale of single application (i.e. plant size or field size)</b></p>	<p>Economics would determine minimum size of installation that would be feasible.</p>
<p><b>Number of deployments at maturity</b></p>	<p>TBD</p>
<p><b>Estimated time to full deployment/ market saturation</b></p>	<p>5 to 30 years depending upon whether an economic driver exists for this purpose.</p>
<p><b>Estimated duration of significant impact</b></p>	<p>Dependent on the availability of pore space, and pressure decline in the gas reservoir</p>
<p><b>Special requirements on CO<sub>2</sub> (purity, etc.)</b></p>	<p>Pure CO<sub>2</sub>, CO<sub>2</sub>/N<sub>2</sub> or CO<sub>2</sub>/CH<sub>4</sub> mixtures can be used, but CO<sub>2</sub> transported over pipeline should be purified to relevant specifications</p>
<p><b>Process/Technology Input Raw Materials and/or Energy</b></p>	<p>Carbon dioxide, electricity</p>
<p><b>Process/Technology Outputs</b></p>	<p>Methane, any co-produced water and CO<sub>2</sub></p>
<p><b>Any concomitant advantages?</b></p>	<p>Produces natural gas</p>
<p><b>Legal/regulatory framework governing/impacting deployment of this option</b></p>	<p>UIC Class II regulations for future wells in the U.S., framework to permit acid-gas injections in Canada.</p>

### 4.4.3 CO<sub>2</sub> Fracturing

CO<sub>2</sub> fracturing refers to the creation of high-permeability pathways for increased natural gas recovery. CO<sub>2</sub> fracturing is one example of ‘energized-fluid fracturing, where a gas component is added to reduce the water content of the fracturing fluid. Energized fractures are used in almost all hydraulic fracturing treatments in depleted tight gas sand formations of North America<sup>22</sup>. They are used in water-sensitive formations (e.g. shale formations containing clays which may swell in the presence of water), depleted or shallow reservoirs. CO<sub>2</sub> has been used in hydraulic fracture stimulation since the 1960's. In energized-fluid fracturing, after completion of the fracturing, reduction of the fluid pressure leads to a rapid increase in the gas permeability because of the lower liquid content of the fracturing fluid, enhancing fluid flowback while the sand particles ‘proppants’ transported by CO<sub>2</sub> into the formation prevent fracture closure. CO<sub>2</sub>-based fracturing fluids minimize the use of viscosity-enhancing polymers in the fracturing fluid. Fluid recoveries in energized-fluid fracturing are considerably higher than that for hydraulic fracturing. CO<sub>2</sub> fracturing is applicable to both conventional ‘tight sandstone’ reservoirs and the ‘tighter’, less-permeable organic shale formations. Kargbo et al.<sup>23</sup> note that nitrogen may also be needed to reduce the formation of ice in the wellbores and to reduce the overall treatment cost.

The issue of fracturing formations to release underground hydrocarbons that can then be recovered has been, and continues to be contentious for the risk it may pose to drinking water supplies, for inducing seismicity, and for other environmental impacts of fluid mixtures used in this process. There have been attempts to bring all of these activities under the aegis of the Safe Drinking Water Act and the Community Right to Know regulations. The changes in practice that might occur if CO<sub>2</sub> (particularly supercritical carbon dioxide) were widely used in lieu of other fluids is not clear at this time. Whether the existing concerns would be ameliorated by this change in practice remains an active question.

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<sup>22</sup> Freihauf, K.E., 2009. Simulation and Design of Energized Hydraulic Fractures. Ph.D. Thesis. Austin, TX: The University of Texas at Austin. Available at: <http://www.pge.utexas.edu/theses09/friehauf.pdf>.

<sup>23</sup> Kargbo, D.M., Wilhelm, R.G. & Campbell, D.J., 2010. Natural Gas Plays in the Marcellus Shale: Challenges and Potential Opportunities. *Environmental Science & Technology*, 44(15), pp.5679-5684.

4.4.3.1 *Dry-Frac CO<sub>2</sub>/sand stimulation Factsheet*

<p><b>Estimated impact /Net CO<sub>2</sub> considered permanently sequestered (US)</b></p>	<p>Uses CO<sub>2</sub>, does not permanently store it</p>
<p><b>Gross current CO<sub>2</sub> consumption in this use (US), MT/year</b></p>	<p>TBD. A typical tight gas vertical well completion in the Western Canadian Sedimentary Basin (WCSB) can require a volume of fluids exceeding 200 cubic meters<sup>24</sup>. Upto 0.4 T of CO<sub>2</sub> could be used per well completion.</p>
<p><b>Projected growth in CO<sub>2</sub> demand for this process</b></p>	<p>TBD. Depends on the rate of maturation of gas reservoirs, and additional demand growth from shale gas drilling</p>
<p><b>Game-changing events/scenarios favorable for this process</b></p>	<p>Regulations that limit the use of water in hydraulic fracturing, limited availability of fresh water, or recycling produced water, increased exploration of shale gas plays and ‘tighter’ conventional sand gas reservoirs</p>



Figure 3. Liquid CO<sub>2</sub> from the truck and the solid proppant are mixed in a closed vessel and used for subsequent fracturing in the Dry-Frac stimulation. Source: Mazza, 2001

In this process, liquid CO<sub>2</sub> is used as the fracturing fluid for proppant transport. Upon fracturing, with the reduction in pressure, the liquid CO<sub>2</sub> vaporizes within the formation leaving no residual fluids and minimizing formation damage. This is useful for fracturing of low-pressure reservoirs, where the hydraulic fracturing flowbacks to the surface can take a long time, increasing water treatment costs. CO<sub>2</sub> fracturing minimizes the

<sup>24</sup> Liao, S., Brunner, F. & Mattar, L., 2009. Impact of Ignoring CO<sub>2</sub> Injection Volumes on Post-Frac PTA. In Proceedings of Canadian International Petroleum Conference. Available at: <http://www.onepetro.org/mslib/servlet/onepetropreview?id=PETSOC-2009-124&soc=PETSOC> [Accessed November 22, 2010].

volume of liquid to be 'swabbed' or treated, prevents clay swelling because it stabilizes the pH to around 3, and allows rapid clean-up of treating fluids. Because dissolved CO<sub>2</sub> is acidic, it may also enhance the permeability of the formation. Trican Well Service in Canada<sup>25</sup> and Universal Well Services in the U.S.A. supply the technology to blend the proppant with liquid CO<sub>2</sub> in a closed container under pressure. In the Dry-Frac stimulation process, liquid CO<sub>2</sub> from a tanker is mixed with the proppant without any additional additives and pumped at high rate into the formation. The Dry-Frac process is best applicable to tighter (less permeable), lower-pressure, dry gas reservoirs (where other stimulation liquids may reduce gas permeability), and also in higher-permeability reservoirs to reduce near-wellbore damage. Nitrogen may also be needed to reduce the formation of ice in the wellbores and to reduce the overall treatment cost. The lack of infrastructure to transport CO<sub>2</sub> and N<sub>2</sub> from their sources (air separation plants, cement plants, power plants) to the fracturing site is an impediment to this process.

#### ***4.4.3.2 CO<sub>2</sub>-Based Fracturing Fluids, Schlumberger***

Other variations in the use of CO<sub>2</sub> as a fracturing fluid include polymer-CO<sub>2</sub> mixtures (e.g. ThermoFOAM<sup>26</sup>) and polymer-free CO<sub>2</sub> fracturing fluids such as ClearFRAC CO<sub>2</sub> viscoelastic surfactant (VES)<sup>27</sup> from Schlumberger. The ClearFRAC CO<sub>2</sub> surfactant was developed for wells requiring 'energized-fluid fracturing' for added fluid flowback and the pressure benefits of hydraulic fracturing with CO<sub>2</sub>. The ClearFRAC CO<sub>2</sub> fluid has low friction pressure and high proppant-carrying capacity, minimizes formation damage and creates longer, more effective fracture half-lengths compared to polymer-CO<sub>2</sub> fracturing fluids. The low-viscosity, high-elasticity features of the fluid are suited for efficient proppant (sand particle) transport into the formation. The ClearFRAC CO<sub>2</sub> stimulant is prepared with 2% potassium chloride (KCl) solution and supercritical CO<sub>2</sub>. An encapsulated emulsion 'breaker', designed for the proppant-laden fracturing stages is added in the slurry stage. Upon pressure release subsequent to fracturing, the foam is destabilized by the breaker and the gas formed enhances fluid flowback to the surface, minimizing damage to the structure of the injected proppant (proppant pack).

#### ***4.4.3.3 Other CO<sub>2</sub> Fracturing Technology Providers***

Other technology providers include Halliburton, and Linde. Linde supplies CO<sub>2</sub> for fracturing fluid formulation in the U.S.A.<sup>28</sup>

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<sup>25</sup> <http://www.trican.ca/Services/technologyfracturingliquidco2.aspx>

<sup>26</sup> [http://www.slb.com/services/stimulation/tight\\_gas\\_stimulation/thermafoam.aspx](http://www.slb.com/services/stimulation/tight_gas_stimulation/thermafoam.aspx)

<sup>27</sup> [http://www.slb.com/resources/other\\_resources/product\\_sheets/stimulation/clearfrac\\_co2.aspx](http://www.slb.com/resources/other_resources/product_sheets/stimulation/clearfrac_co2.aspx)

<sup>28</sup> [http://www.lindegasbenelux.com/international/web/lg/us/likelgus30.nsf/docbyalias/nav\\_frac\\_co2#1](http://www.lindegasbenelux.com/international/web/lg/us/likelgus30.nsf/docbyalias/nav_frac_co2#1)

#### 4.4.4 Enhanced Coal-Bed Methane (ECBM) Recovery

ECBM refers to the production of methane (CH<sub>4</sub>) by injecting gases such as CO<sub>2</sub> and N<sub>2</sub>. The injection of CO<sub>2</sub> into unmineable coal seams results in methane production because CO<sub>2</sub> interacts more strongly with the coal matrix than CH<sub>4</sub>. The definition of what coal seams are unmineable may vary, but coal-bed depths of 100 to 1,500 m and thin coal seams (less than 10 m) are usually considered for CO<sub>2</sub>-ECBM. Methane not recovered by primary recovery techniques such as dewatering and depressurization can be recovered by sweeping the coal bed with CO<sub>2</sub>. Although natural gas prices in the U.S. are currently low, coal bed methane recovery has economic potential in other parts of the world, and could offset CO<sub>2</sub> storage costs. A 2003 study<sup>29</sup> (Reeves, 2003) on the storage potential of U.S. coal beds noted a capacity of 90 GT CO<sub>2</sub> (90 billion metric tonnes). Reeves further noted that approximately a third of this potential storage capacity of CO<sub>2</sub> could be stored at a net benefit to the operator (excluding CO<sub>2</sub> capture and transportation cost). A large portion of the U.S. ECBM potential is in Alaska (38 GT CO<sub>2</sub>). More recent assessments indicate a technical CO<sub>2</sub> storage potential of 60 to 117 billion tonnes of CO<sub>2</sub><sup>30</sup>. Also, storage in marginal coal bed prospects (at a net cost to the operator) perhaps may not constitute a beneficial use of CO<sub>2</sub>. Finally, there is significant variability in the estimates of CBM, and by extension, ECBM, because the amount of methane in the coal and the fraction of that methane displaced by CO<sub>2</sub> is not quantified using consistent methodologies. CO<sub>2</sub>-ECBM has been tested at pilot scale in the U.S. (San Juan Basin), Canada (Alberta Basin), Poland (RECOPOL project), China (Qinshui Basin) and Japan (Hokkaido). The permeability of the coal matrix to fluid flow decreases upon swelling due to CO<sub>2</sub> injection. Pilot-scale tests indicate that the swelling-shrinkage phenomena have considerable effects on the transport of CO<sub>2</sub> and methane in the coal bed.

##### 4.4.4.1 CO<sub>2</sub>-Enhanced Coal Bed Methane Recovery Factsheet

<b>Estimated impact /Net CO<sub>2</sub> considered permanently sequestered (US)</b>	U.S. estimates of CO <sub>2</sub> storage range from 60 to 110 billion T CO <sub>2</sub> . Net CO <sub>2</sub> beneficially stored (at a profit) would be lower, ~30 billion T CO <sub>2</sub> could be beneficially stored.
<b>Gross current CO<sub>2</sub> consumption in this use (US), MT/year</b>	Pilot tests, no current large-scale operations
<b>Projected growth in CO<sub>2</sub> demand for this process</b>	TBD
<b>Game-changing events/scenarios favorable for this process</b>	Overcoming coal swelling

<sup>29</sup> Reeves, S.R., Assessment of CO<sub>2</sub> Sequestration and ECBM Potential of US Coalbeds, Topical Report, DOE Contract No. DE-FC26-00NT40924, February 2003.

<sup>30</sup> [http://www.netl.doe.gov/technologies/carbon\\_seq/refshelf/atlasIII/](http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasIII/), Accessed November 2010.

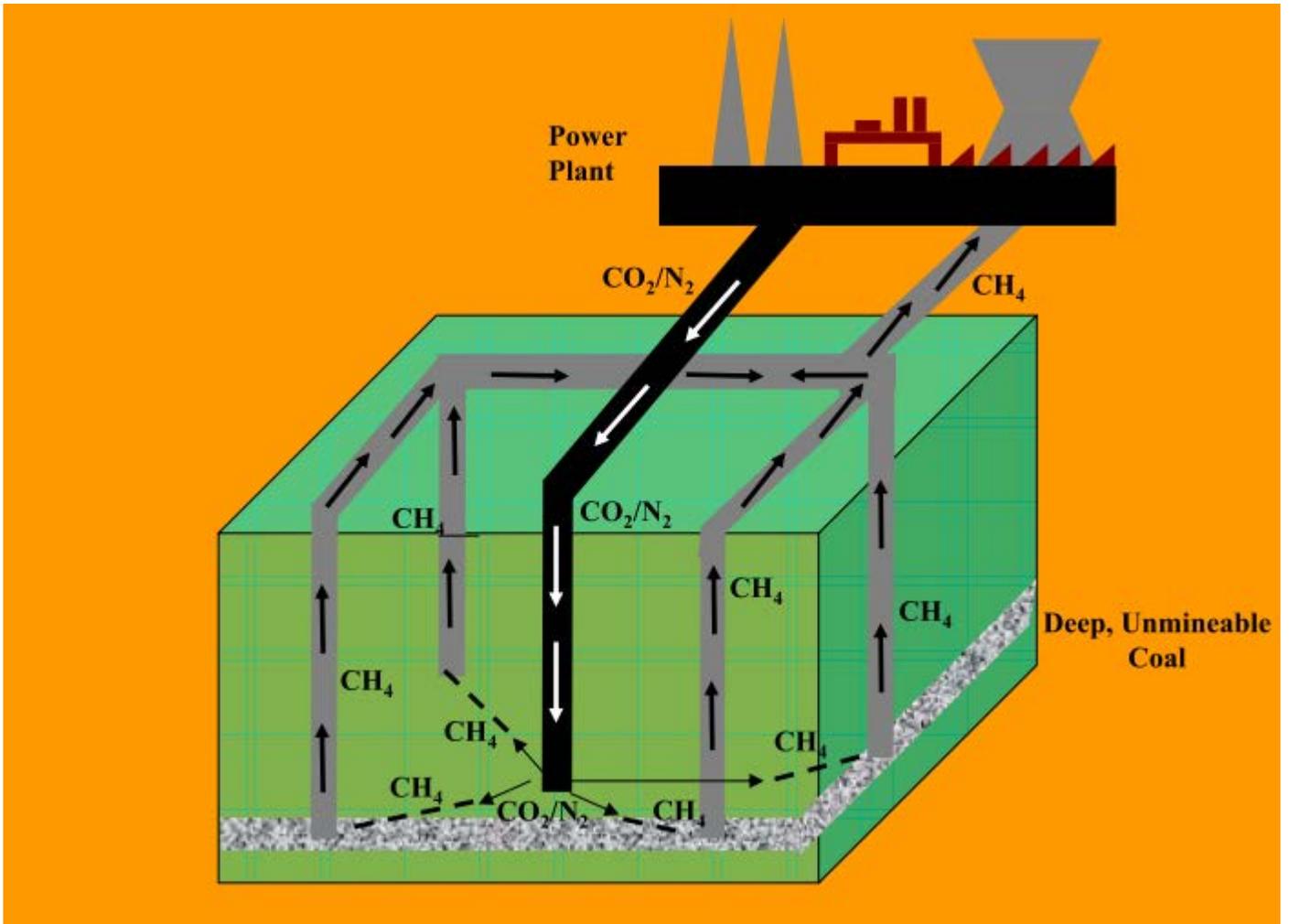


Figure 4. Illustration of CO<sub>2</sub>-ECBM operation

<b>Estimated scale of single application (i.e. plant size or field size)</b>	Economics would determine minimum size of installation that would be feasible.
<b>Number of deployments at maturity</b>	May be limited to fields proximate to CO <sub>2</sub> pipelines or sources
<b>Special requirements on CO<sub>2</sub> (purity, etc.)</b>	Pure CO <sub>2</sub> , CO <sub>2</sub> /N <sub>2</sub> mixtures may be used. N <sub>2</sub> flushes CH <sub>4</sub> and results in quicker breakthrough
<b>Process/Technology Input Raw Materials and/or Energy</b>	Carbon dioxide, electricity
<b>Process/Technology Outputs</b>	Methane, co-produced water and CO <sub>2</sub>
<b>Any concomitant advantages? (For example, Does this process eliminate the need for other pollution control equipment?)</b>	Produces natural gas, has indirect CO <sub>2</sub> reduction impacts
<b>Legal/regulatory framework governing/impacting deployment of this option</b>	UIC Class II regulations for future wells in the U.S.A.

#### 4.4.5 Recovery of Natural Gas from Gas Hydrate Using CO<sub>2</sub>

Clathrate hydrates are solid crystalline inclusion compounds formed when water is contacted with small molecules (guests) under certain temperature and pressure conditions. When the guests are comprised of methane or other natural gas components, clathrate hydrates are referred to as gas hydrates. Clathrate hydrates are comprised of a guest molecule encapsulated in a cage-like structure of water ice. They occur both onshore (shallow permafrost settings) and offshore (continental margins). Estimates of global methane hydrate resources are of the order of 10<sup>15</sup> cubic meters. Within the continental U.S., the USGS estimated that the Alaska North Slope (ANS) contains 590 trillion cubic feet (TCF) (or 17x10<sup>12</sup> m<sup>3</sup>) of gas-in-place<sup>31</sup>. Of this, approximately 85 TCF may be technically recoverable by being in close proximity to existing oil and gas production infrastructure. The dissociation of methane hydrates requires energy, and is self-limiting if depressurization is employed as the only recovery technique. Various thermal stimulation techniques including hot brine injection, steam injection, and microwave-enhanced recovery have been proposed to extract methane. All of them are at a conceptual level and may incur significant energy penalties to heat and dissociate the methane hydrate.

A wide range of values for the amount of methane-in-place recovered have been reported by previous laboratory-scale experimental studies. Recent modeling studies (based on data from pilot tests) on the 'Eileen' gas hydrate accumulation in Alaska indicate that up to 2.5 TCF of the 33 TCF of gas-in-place at 'Eileen' may be produced in 20 years if depressurization was successfully employed<sup>32</sup>. One technique which is relevant for the purposes of this discussion is the injection of CO<sub>2</sub> to form CO<sub>2</sub> hydrate by displacing methane. Both CO<sub>2</sub> and CH<sub>4</sub> form 'Structure I' hydrates, although the number of water molecules encapsulating the guest molecule may vary from 5 to 7<sup>33</sup>. Each molecule of methane produced would be substituted by a molecule of CO<sub>2</sub>. This is advantageous, because the formation of CO<sub>2</sub> hydrate releases more energy than that consumed by the breakup of CH<sub>4</sub> hydrates<sup>34</sup>. This concept has been a subject of various journal articles<sup>35,36</sup> and patents<sup>37,38</sup>. One

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<sup>31</sup> Hunter R., Lewis, S., Resource Characterization and Quantification of Natural Gas Hydrate and Associated Free-Gas Accumulations in the Prudhoe Bay – Kuparuk River Area on the North Slope of Alaska, 2Q2010-3Q2010 Semi-Annual Progress Report, Available at: [http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/2010Reports/NT41332\\_SemiAnnApr-Sep2010.pdf](http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/2010Reports/NT41332_SemiAnnApr-Sep2010.pdf), [Accessed December 2, 2010].

<sup>32</sup> Wilson, S.J. et al., Alaska North Slope regional gas hydrate production modeling forecasts. Marine and Petroleum Geology, In Press, Corrected Proof. Available at: <http://www.sciencedirect.com/science/article/B6V9Y-4YMPXBH-1/2/6a47c6322e7c6c18fab05573d2c1e270> [Accessed December 3, 2010].

<sup>33</sup> Birkedal, K.A., 2009. Hydrate Formation and CH<sub>4</sub> Production from Natural Gas Hydrates - Emphasis on Boundary Conditions and Production Methods. Master's Thesis. Norway: University of Bergen. Available at: <https://bora.uib.no/bitstream/1956/3425/1/56365022.pdf> [Accessed December 3, 2010].

<sup>34</sup> McGrail, B.P. et al., 2007. Using Carbon Dioxide to Enhance Recovery of Methane from Gas Hydrate Reservoirs: Final Summary Report, PNNL-17035, Available at: <http://www.osti.gov/bridge/servlets/purl/929209-jP39G7/> [Accessed December 2, 2010].

<sup>35</sup> See for example: Baldwin, B.A. et al., 2009. Using magnetic resonance imaging to monitor CH<sub>4</sub> hydrate formation and spontaneous conversion of CH<sub>4</sub> hydrate to CO<sub>2</sub> hydrate in porous media. Magnetic Resonance Imaging, 27(5), pp.720-726.

<sup>36</sup> See for instance: Ikegawa, Y. et al., 2010. SS: Hydrates: Experimental Results for Long Term CO<sub>2</sub> Injection Near Methane Hydrate Formations. In Proceedings of Offshore Technology Conference. Offshore Technology Conference. Available at: <http://www.onepetro.org/mslib/servlet/onepetropreview?id=OTC-20575-MS&soc=OTC> [Accessed December 2, 2010].

<sup>37</sup> See for example: Sivaraman, A., 2005. Process to sequester CO<sub>2</sub> in natural gas hydrate fields and simultaneously recover methane. Available at: <http://uspto.gov> [Accessed December 3, 2010].

<sup>38</sup> See for instance: Lyon, R.K., 2004, United States Patent: 6733573 - Catalyst allowing conversion of natural gas hydrate and liquid CO<sub>2</sub> to CO<sub>2</sub> hydrate and natural gas. Available at: <http://uspto.gov> [Accessed December 3, 2010].

*Draft*

proposed process involves the injection of microemulsions of liquid CO<sub>2</sub> and water into gas hydrate-bearing formations resulting in the breakup of methane hydrate and the formation of CO<sub>2</sub> hydrate, thereby storing CO<sub>2</sub> and producing methane. McGrail et al. note that injection of liquid CO<sub>2</sub>-water emulsion at high pressures (~1,000 psia) results in a three-fold increase in methane production compared to the injection of cold water alone. If natural gas beneath the gas hydrate accumulation contains appreciable quantities of CO<sub>2</sub>, and can be easily processed, the separated CO<sub>2</sub> could possibly be injected into the hydrate zone to enhance the production of methane<sup>39</sup>. Many parameters of this process critical to pilot, or experimental investigations are poorly understood, because the concept is in the developmental stage.

The U.S. DOE, ConocoPhillips and Japan Oil, Gas and Metals National Corporation (JOGMEC) are currently conducting a test of hydrate production by injecting CO<sub>2</sub> into gas hydrate reservoirs. Approximately 210,000 standard cubic feet (scf) of CO<sub>2</sub>/N<sub>2</sub> gas blend was injected into the hydrate-bearing Sagavanirktok "C" sandstone at the Ignik Sikumi #1 well. Initial injection rate was ~11,000 scf per day, and gradually increased to ~21,000 scf per day during thirteen days of injection. The primary test target, the Sagavanirktok "Upper C" sandstone (2,214 to 2,274 ft below the rig floor) contains 44 feet of clean, high-porosity sandstone rock with very high concentrations of gas hydrate in the optimal pressure-temperature conditions. Post-injection flowback operation is being continued at Ignik Sikumi #1<sup>40</sup>.

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<sup>39</sup> Goel, N., 2006. In situ methane hydrate dissociation with carbon dioxide sequestration: Current knowledge and issues. *Journal of Petroleum Science and Engineering*, 51(3-4), pp.169-184.

<sup>40</sup> [http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/rd-program/ANSWell/co2\\_ch4exchange.html](http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/rd-program/ANSWell/co2_ch4exchange.html)

#### 4.4.6 Oil Shale

##### Process Discussion: Use of Supercritical CO<sub>2</sub> in oil shale and tar sands

Extracting hydrocarbons from either Canadian tar sands or from oil shale formations represent significant commercial or near-commercial activities amongst a number of unconventional hydrocarbon extraction processes. There is on-going commercial production of heavy liquids from the tar sands deposits in Canada. Recent announcements in the U.S. indicate that commercial development of oil shale in the U.S. won't occur for some time – perhaps 15 years or longer<sup>41</sup>. Oil shale deposits have been used to produce hydrocarbon liquids in Estonia for many years and Brazil has continued to develop surface retorting technology applicable to the deposits found there<sup>42</sup> (see Figure 5). Oil shale deposits are found in many places in the world, although the greatest known concentrations occur in the United States. One location in China, the Ordos basin, is also being actively examined as a location for carbon sequestration sites. It is also necessary, for clarity, to point out the distinction between crude oil found in shale deposits (including the Bakken shale in the upper Midwest and central Canadian Province, and the Eagle Ford deposit in southwest Texas) and oil shale, rock formations containing kerogen. Kerogen is an organic precursor to petroleum, composed of algae and woody plant material that have been geologically trapped<sup>43</sup>.

There are several connections between tar sands or oil shale and the use or storage of carbon dioxide. First, patents have been granted for various processes which use supercritical carbon dioxide to release and react with the kerogen within the formation to produce hydrocarbon liquids that can then be extracted from oil shale formations. US patent US7500517, describes a process involving the use of liquid and solid carbon dioxide to extract hydrocarbons from kerogens. As described in the patent, one possible approach would be to fracture and rubblize subsurface shale formations in order to enhance permeability of the formation. This effect can be produced by drilling a well into the formation and injecting a slurry of liquid carbon dioxide and solid carbon dioxide then sealing the injection well. Once sealed, the two forms of carbon dioxide are to interact to form a single supercritical phase and to pressurize the well. Subsequent depressurization of the well produces adiabatic expansion of the carbon dioxide which cools the subsurface formation. The resulting thermal and mechanical stresses are claimed, in the patent, to occur and to fracture the formation facilitating subsequent extraction. The patent also claims that in some embodiments, the hydrocarbon so released can be chemically reacted (cracked) in ways that render it mobile and readily extracted<sup>44</sup>.

In 2008, Schlumberger acquired the technology developed by Raytheon and CF Technologies for production of liquids from oil shales<sup>45</sup>. The technology developed to be used in oil shale processing combines radio frequency (RF) technology with critical fluid (CF) technology.

Raytheon has projected that the same process could also be used to retrieve oil from Canadian oil sands and to reprocess spent wells. Carbon dioxide is commonly considered as the supercritical fluid<sup>46</sup> to be used.

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<sup>41</sup> Huffington Post article, February 2010

<sup>42</sup> See: [http://www.searchanddiscovery.com/documents/2009/30083nummedal/ndx\\_nummedal.pdf](http://www.searchanddiscovery.com/documents/2009/30083nummedal/ndx_nummedal.pdf)

<sup>43</sup> See both <http://seekingalpha.com/article/235257-oil-shale-shale-oil-and-6-ways-to-play-the-difference> and <http://www.glossary.oilfield.slb.com/Display.cfm?Term=kerogen>

<sup>44</sup> US patent 7500517, Looney, et al., March 10, 2009

<sup>45</sup> See: <http://www.greencarcongress.com/2008/01/schlumberger-ac.html> as cited in <https://alum.mit.edu/discuss/thread.jspa?messageID=8737&tstart=0>

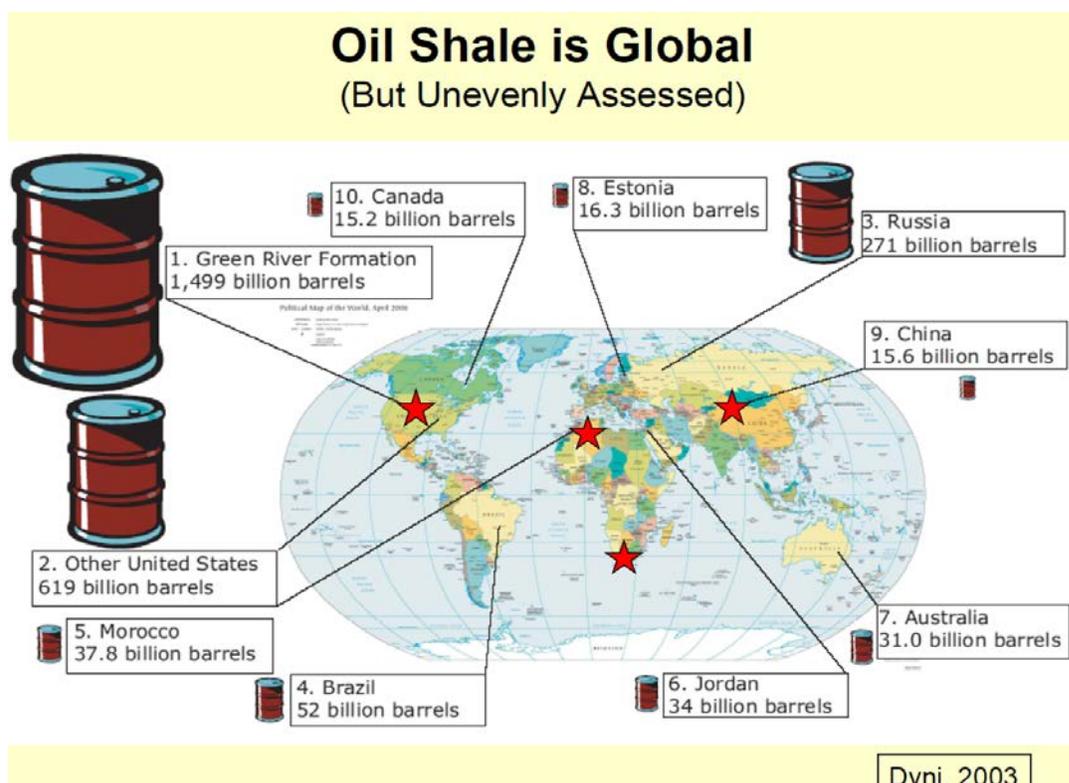


Figure 5. Global oil shale formations (see Nummedal, et al, 2009)

Carbon dioxide has also been studied for its action as a recently developed solvent capable of this chemical transformation. A paper from 2001<sup>47</sup> describes the potential role of carbon dioxide compared to other organic solvents in treatment of oil shale samples. According to the authors, “Supercritical fluid extraction (SFE) with carbon dioxide is particularly effective for the isolation of substances of medium molecular weight and relatively low polarity. At elevated temperatures it is possible to unite the breaking chemical bonds in the kerogen organic matter and convert the former into oil with extraction using supercritical fluids.”

Similarly, there are patents in the literature for means to process tar sands. For instance, U.S. patents 4341619<sup>48</sup> and 4565248<sup>49</sup> describe methods for extracting liquids from tar sands using either direct injection of supercritical fluids (such as carbon dioxide) or of a mixture of carbon dioxide and steam. Neither of these patents discusses the fate of the carbon dioxide after recovery of the bitumen. However, it is likely that much of the carbon dioxide could return to the surface with the bitumen and would need to be reinjected into a formation to be sequestered.

<sup>46</sup> See: Raytheon brochure: Radio Frequency/Critical Fluid Oil Extraction Technology (2006)

<sup>47</sup> M. Koel, S. Ljovin, K. Hollis, and J. Rubin, Using neoteric solvents in oil shale studies, *Pure Appl. Chem.*, Vol. 73, No. 1, pp. 153–159, 2001

<sup>48</sup> US patent 4341619, Poska, July 27, 1982

<sup>49</sup> US patent 4565249, Pebdani and Shu, January 21, 1986

*Draft*

In 2008, Lawrence Livermore National Laboratory (LLNL) and American Shale Oil (AMSO) announced a technical cooperation agreement to explore development of carbon sequestration technologies applicable to in-situ shale-oil production processes. The organizations agreed to partner in a study of means to permanently store carbon dioxide generated during the oil shale extraction process in depleted underground oil shale formations<sup>50</sup>.

In order to develop a sense for the quantities of carbon dioxide that could be involved in recovery of either oil shale liquids or bitumen, the Pebdani patent<sup>51</sup> discusses some typical results from limited field tests for tar sands: an article by L.C. Leung<sup>52</sup> based on simulation studies reported that for a series of steam injection rates, injection of carbon dioxide at a ratio of 400 SCF/bbl of steam (cold water equivalent) yielded a 36% improvement in recovery. And an article by Redford (1982)<sup>53</sup> reported that the optimum CO<sub>2</sub> to steam ratio, based on injection tests, was approximately 197 SCF/bbl of steam (cold water equivalent). The Pebdani patent reported data from limited tests using steam and carbon dioxide in a “huff and puff” approach and showed optimum increases in liquid recovery when injecting 300 SCF of carbon dioxide per barrel of steam (estimated on equivalent liquid water volume). Using these data, one can estimate that approximately 0.05 tons of carbon dioxide would be used per barrel of hydrocarbon liquid produced (see the figure below).

Estimating average values for the amount of kerogen per ton of rock, threshold values start at 15 gallons per ton. Very rich deposits can have up to 100 gallons per ton. Estimates of water usage for processing vary but could be in the range of 1 (or less) to 3 barrels of cold water per barrel of hydrocarbons produced for the in-situ extraction step. Coupling these estimates with the carbon dioxide/steam ratios given above, the amount of carbon dioxide per barrel of liquid might range from 150 SCF/barrel of liquid to 1,000 SCF/ barrel. This does not include the injection of carbon dioxide for any other purpose (such as creating a frozen barrier to ground water intrusion).

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<sup>50</sup> See: <http://www.businesswire.com/news/home/20081203005851/en>

<sup>51</sup> Ibid Pebdani, page 3

<sup>52</sup> L.C. Leung, Numerical Evaluation of the Effect of Simultaneous Steam and CO<sub>2</sub> Injection on the Recovery of Heavy Oil, *J. Pet. Tech.*, p. 1591 (September 1983)

<sup>53</sup> D.A. Redford, The Use of Solvents and Gases with Steam in the Recovery of Bitumen from Oil Sands, *J. Can. Pet. Tech.*, p. 45 (January-February 1982)

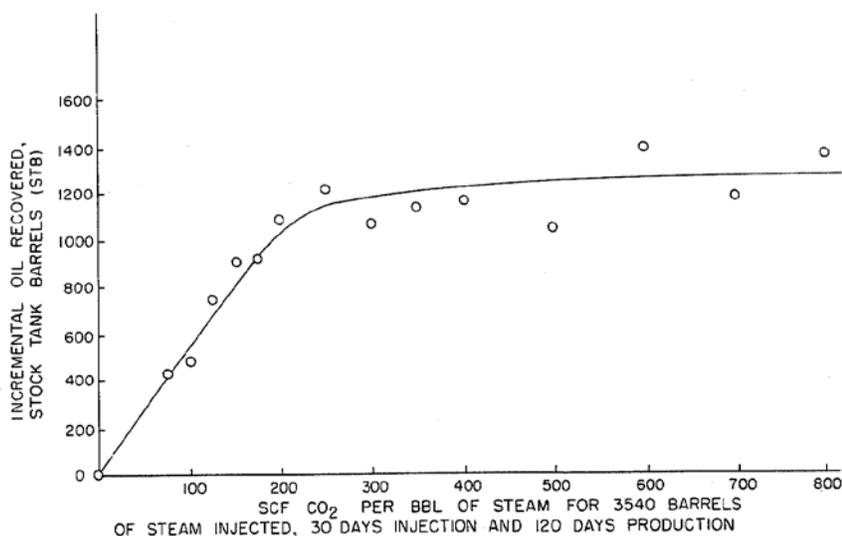


Figure 6. Field test data from Pebdani, et al.

Researchers at the University of Victoria, Canada (Fadaei et al., 2012)<sup>54</sup> report the development of a microfluidics-based rapid testing methodology for evaluating the behaviour of CO<sub>2</sub> in bitumen reservoirs, such as Canada's oil sands. Supplementing steam injection by CO<sub>2</sub> for the extraction of crude from bituminous oil sands has the potential to lower the CO<sub>2</sub> emissions directly and indirectly.

At present, closed loop applications that would employ carbon dioxide in any of the processes described above have not been engineered or studied in terms of life cycle emissions. Such an analysis would need to include: (a) carbon dioxide used as a solvent then released during separation of the hydrocarbon liquids from the solvents and other production fluids; and, (b) any carbon dioxide generated from energy production facilities needed to supply either electricity (for example for the RF technologies) or to produce steam.

#### 4.4.7 Enhanced Recovery of Shale Gas Using CO<sub>2</sub>

The use of CO<sub>2</sub> to enhance the recovery of methane trapped in gas shales has some similarities with ECBM in that CO<sub>2</sub> is adsorbed preferentially compared to methane. However, this is a relatively less-mature process. Capacity estimates and preliminary reservoir modeling studies are being conducted for various gas shales. A study by ARI (Petrusak, 2011)<sup>55</sup> provides preliminary estimates of gas production and CO<sub>2</sub> storage by CO<sub>2</sub> injection in the Marcellus and Utica shales of New York state. The gas-in-place (GIP) was estimated to be 579 Tcf, and theoretical maximum CO<sub>2</sub> storage capacity was calculated to be 519 Tcf. Preliminary reservoir modeling results indicate methane recovery would be 1 to 11% of GIP, and CO<sub>2</sub> storage capacity to be 3 to

<sup>54</sup> Fadaei, H., Scarff, B. & Sinton, D., 2011, Rapid Microfluidics-Based Measurement of CO<sub>2</sub> Diffusivity in Bitumen, *Energy Fuels*, 25(10), pp.4829–4835.

<sup>55</sup> Petrusak, R., 2011, Assessing Factors influencing CO<sub>2</sub> storage capacity and injectivity in gas shales – Review of current activities, Presented at the 7<sup>th</sup> International Forum on Geological Sequestration of CO<sub>2</sub> in Coal Seams and Gas Shale Reservoirs, March 7-8, 2011, Houston, TX, Available at: [http://coal-seq.com/proceedings2011/presentations/8\\_Robin%20Petrusak\\_ARI.pdf](http://coal-seq.com/proceedings2011/presentations/8_Robin%20Petrusak_ARI.pdf) [Accessed: 10/19/2011].

20% of the theoretical maximum for both Marcellus and Utica shale plays. This is equivalent to 17 to 111 MT/y of CO<sub>2</sub> storage in the Marcellus shale and 10 to 68 MT/y CO<sub>2</sub> storage in the Utica shale (over 30 years). These quantities are likely to be revised as shale gas operators develop a better understanding of CO<sub>2</sub> storage and enhanced gas recovery from shales.

## **5 Reuse (Non-Consumptive) Applications**

### **5.1 Introduction: Re-use (Non-Consumptive) Applications**

Applications where CO<sub>2</sub> is not consumed directly, but re-used or used only once are categorized as CO<sub>2</sub>-reuse. The main applications in this category are:

- Use of CO<sub>2</sub> for desalination,
- Use of CO<sub>2</sub> as a working fluid,
- Production of fuels and chemicals.

The CO<sub>2</sub>-desalination process for brackish or saline water is based on the principle of exclusion of large dissolved ions when CO<sub>2</sub> hydrates are formed. In the gas hydrate structure, water molecules form a network of cages that are occupied by individual gas molecules, eliminating all other dissolved ions. The salt content of the water forming the hydrate phase is lowered considerably in the process. Formation and subsequent dissociation of CO<sub>2</sub> hydrates in saline water leads to the reduction of salinity and the production of fresh water. High-pressure and relatively high-purity CO<sub>2</sub> would likely be needed for this process. The benefits from CO<sub>2</sub>-desalination processes result from the production of fresh water for general plant use and sale in areas otherwise lacking fresh water supplies, and any potential CO<sub>2</sub> offsets generated by geologic or oceanic sequestration. The value of generating potable water is two-fold. Firstly, the economic value could be substantial, offsetting a portion of the CCS costs. Secondly, potable water shortages are a significant concern in various parts of the world, and generating potable water may provide a means to adapt to climate change.

CO<sub>2</sub> can also be used as a ‘working fluid’ in freight pipelines, for the beneficiation and recovery of valuable metals such as rare earths, as a superior heat transfer fluid in power plants, as a ‘green’ solvent (for example as an alternative to some current tar sands processing technologies), and as a slurry transport medium for gasifier solid feeds. The primary benefits from this category of applications include avoided-CO<sub>2</sub> emissions, and concomitant cost savings resulting from higher efficiencies.

Finally, CO<sub>2</sub> can also be used to produce fuels and chemicals such as methanol, formaldehyde, and other polymer precursors. Unlike the other applications in the non-consumptive use category, the production of fuels and chemicals chemically transforms CO<sub>2</sub>. The primary benefits from this application involve avoided-CO<sub>2</sub> emissions as a result of carbon recycling, the value of the produced chemical, and any potential long-term sequestration in inert organic polymers.

### **5.2 Metrics: Non-Consumptive Applications**

Non-consumptive CO<sub>2</sub>-use applications have an indirect-CO<sub>2</sub> reduction benefit in the form of production of fresh water or valuable minerals, higher efficiency, or the displacement of fossil fuels. Seven non-consumptive uses were discussed in the report: desalination, beneficiation, slurry transport, heat transfer fluid, freight pipelines, solvent extraction, and the conversion of CO<sub>2</sub> to fuels and chemicals. The use of CO<sub>2</sub> for

supercritical fluid extraction is a commercial-scale process used commercially. The rest of the processes are relatively less-technologically mature, and require research and development.

Table 6 provides a summary of the processes and applications that were reviewed. Where more information was available a “factsheet” was developed to provide a summary of information.

Table 6. Non-Consumptive Applications: Use of CO<sub>2</sub> for Desalination and as a Working Fluid

	CO <sub>2</sub> Mitigation		Benefits	Energy penalty/CO <sub>2</sub>	Market Potential
	(A) CO <sub>2</sub> Reduced (total)	(B) Captured CO <sub>2</sub> used	Value of by-products		(4) Market size (potential tonnage removed from atmosphere)
<b>Desalination</b>	See (A). Primary reductions from indirect-carbon avoidance	5 kg of supercritical CO <sub>2</sub> would produce 50 kg of potable water. <sup>56</sup>	Excess potable water could be sold.	To be assessed on a case-by-case basis	Market potential to be determined by indirect reductions in CO <sub>2</sub> emissions
<b>Freight Pipelines</b>		Amount consumed or sequestered ~zero	NA		
<b>Beneficiation</b>					
<b>Heat Transfer Fluid</b>		Solvent recycled	Solvent extraction can yield commercially valuable materials such as rare earths		
<b>Solvent Extraction</b>					
<b>Feed solids to gasifiers or for slurry transport</b>		Amount consumed or sequestered ~zero	NA		

<sup>56</sup> Sheps, preliminary data

### 5.3 CO<sub>2</sub> Clathrate-Based Process for Desalination of Brackish/Saline Water

It has long been known that clathrates can be formed by a variety of compounds, including refrigerants, light hydrocarbons and carbon dioxide. This property has been seized on to develop concepts for purification of seawater and brackish waters. A number of reports have been written and several patents have been filed on processes to treat waste water, brackish water, and to desalinate sea water. A report by McCormack and Anderson<sup>57</sup> examined a number of options including the use of refrigerants, such as R141B and R22, several hydrocarbons, and carbon dioxide. They evaluated the refrigerants in particular, dismissing carbon dioxide largely due to the costs involved in compressing CO<sub>2</sub> to the necessary operating pressure for clathrate formation – 900 psia.

With the heightened interest in carbon dioxide capture, transportation and sequestration, the compression issue has potentially become a less-critical barrier as carbon dioxide compression would be part of the CCS process, and this may be taken advantage of. However, the process development step is still challenging and typically involves hydrate ice formation, a crystallization process that is difficult to carry-out reliably in continuous, high throughput reactors. The report, Desalination Utilizing Clathrate Hydrates (LDRD Final Report), from Sandia (SAND2007-6565)<sup>58</sup> provides a literature survey of recent research studies and process issues as does the McCormack and Anderson paper (up to 1995).

Among recent patents, US 6,991,722 B2 (Michael Max)<sup>59</sup> and US 2007/0004945 A1 (ORNL)<sup>60</sup> detail approaches to develop a practical process. MDS, a company working to commercialize the Max patent, received FE funding to pursue their approach and built a bench-scale unit. They provide a chart of the relationship between the amount of water that could be processed per cycle and the amount of carbon dioxide utilized (Figure 7).

The primary conclusion of the McCormack and Anderson study was that a clathrate-based process could be attractive if key issues were resolved. Secondary to that conclusion was their assessment that most work to date rushed to the pilot-scale too quickly before the critical processes steps could be developed and refined sufficiently to meet the required commercial performance criteria. For the refrigerants they considered, there were several probable benefits compared to flash desalination and to reverse osmosis. In general, this pathway is still in the early developmental stage although at least one company appears to be moving ahead based on their patented approach (MDS, see <http://www.mdswater.com/OurTechnology.html> and <http://www.aquaventus.com/>).

The MDS technology does not include the capture of carbon dioxide from the gas stream in an energy system. It reuses pressurized CO<sub>2</sub> to purify either waste water or saline waters - including sea water – and to produce a by-product of commercial value.

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[http://www.netl.doe.gov/technologies/carbon\\_seq/core\\_rd/storage.html](http://www.netl.doe.gov/technologies/carbon_seq/core_rd/storage.html)

Desalination Plant – Preliminary Research Study, Water Treatment Technology Program Report No. 5, U.S. Department Of The Interior, Bureau of Reclamation, Technical Service Center, Water Treatment Engineering and Research Group.

<sup>58</sup> Simmons, B.A. et al., 2008. Desalination utilizing clathrate hydrates (LDRD final report, SAND2007-6565, Sandia National Laboratories), Available at: <http://www.osti.gov/bridge/servlets/purl/934586-mQC25H/> [Accessed October 26, 2010].

<sup>59</sup> Max, M.D., 2006. Hydrate Desalination for Water Purification. US 6,991,722 B2

<sup>60</sup> Phelps, T.J. et al., 2005. Method for excluding salt and other soluble materials from produced water. US 2007/004945 A1, [Accessed October 26, 2010].

One industrial application of the ion exclusion during the formation of hydrates is the treatment of wastewater produced in a power plant. In integrated gasification combined cycle (IGCC) power plants, a stream of sour water containing chloride, and traces of ammonia, hydrogen sulfide and other compounds is produced from synthesis gas scrubbing and further acid-gas recovery steps. Another industrial application of this technology is the treatment of brackish brines produced during mining, hydrocarbon recovery, or CO<sub>2</sub> sequestration to produce fresh water which could be used for human consumption or for process uses. James and McGurl (2004)<sup>61</sup> discussed a scenario where a small portion of the desalinated water could be used for wet cooling, general plant consumption, and the rest could be sold as potable water...

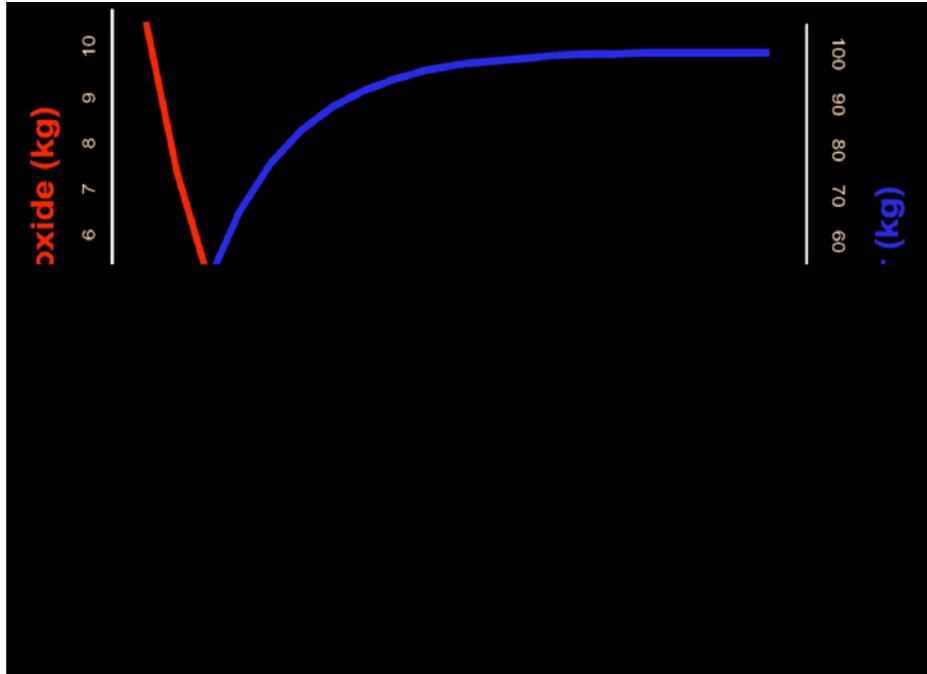


Figure 7. Relationship between the amount of CO<sub>2</sub> utilized and the desalinated water processed per cycle.  
Source: MDS

The impact of this technology depends on whether the deep ocean storage version of this concept, in which the clathrates are formed and broken at depth, providing pressure control over the small range of pressure and temperature swings needed to drive the key step, can be pursued. Alternately, terrestrial applications present a different set of challenges that would need to be overcome prior to deployment of any of the nascent concepts. One non-technical issue that would need to be addressed deals with ownership of the produced water and whether a power plant could discharge the potable water into a stream and sell the rights to pump the water out downstream. This water would not be considered natural water and might not fall under either state or EPA regulations.

In order to develop a rough sense of the potential benefits, the paper by James and McGurl can serve as a point of reference. This system study sought to utilize all of the captured CO<sub>2</sub> (at 90% rate of capture) from a nominal

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<sup>61</sup> James, R.E. & McGurl, G.V., 2004. IGCC System Analysis Utilizing Various Condenser Cooling Platforms, Including CO<sub>2</sub> Sequestration and Water Desalination. Proceedings of the Water Environment Federation, 2004, pp.720-737(18).

425 MWe IGCC unit (based on gross fuel input), producing 23.6 million gallons of water per day. , The sale of excess potable water could offset all costs involved in the production of the water (including costs for the additional equipment and any energy costs associated with the unit). Water production costs using this method are marginally less than costs for a comparable reverse osmosis unit at the time of this study and could offset some of the increased costs for the addition of the carbon capture and storage system, which is beneficial in arid regions.

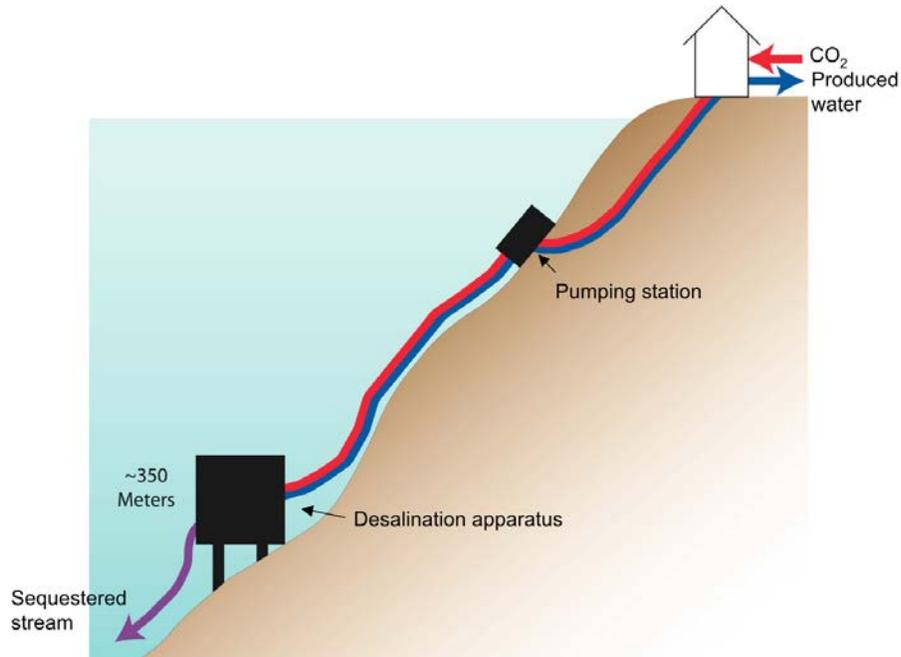


Figure 8. Conceptual application for CO<sub>2</sub> Hydrate Desalination with oceanic disposal of CO<sub>2</sub> (Source: MDS<sup>62,63</sup>).

This approach also represents an opportunity to use saline water that might be produced from sequestration. In order to avoid issues of either over-pressuring a formation or, more likely, to reduce the risk of trespass or the need to secure underground rights to a far greater area of impact (carbon dioxide plus displaced saline water), production of potable water could be a useful option. Because this approach has not been demonstrated as a continuous unit at a modest pilot-scale, potential applications must await further development as must assessments of the potential for applications either at coastal plants or in-land. Further calculations of the benefits of deploying some variant on this process to manage saline waters must await development of a commercially viable process.

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<sup>62</sup> Sheps, K., 2007. Seawater Desalination as a Factor of Oceanic CO<sub>2</sub> Disposal. Presented at CHEMRAWN XVII and ICCDU-IX Conference on Greenhouse Gases - Mitigation and Utilization, Kingston, Ontario, 8 – 12 July 2007. Available at: <http://www.chem.queensu.ca/Conferences/CHEMRAWN/Sheps.pdf> [Accessed October 26, 2010].

<sup>63</sup> Sheps, K. et al., 2009. A case for deep-ocean CO<sub>2</sub> sequestration. *Energy Procedia*, 1(1), pp.4961-4968.

The basic concept depicted, CO<sub>2</sub> Hydrate Desalination, is based on developing and applying oceanic in-situ industrial crystallization. In this approach, the hydrate growth rejects a number of contaminants found in the source water such as dissolved ions, chemicals and small particulates.

### 5.3.1 CO<sub>2</sub> Clathrate Desalination of Brackish/Saline Water Factsheet

<b>Estimated impact /Net CO<sub>2</sub> considered permanently sequestered (US)</b>	None, but would enable production of potable water in areas where only saline water is available with concurrent economic benefit.
<b>Gross current CO<sub>2</sub> consumption in this use (US), MT/year</b>	None
<b>Game-changing events/scenarios favorable for this process</b>	Regulations that either impact access to pore space or that restrict the use of cooling water or that facilitate use of treated saline waters.

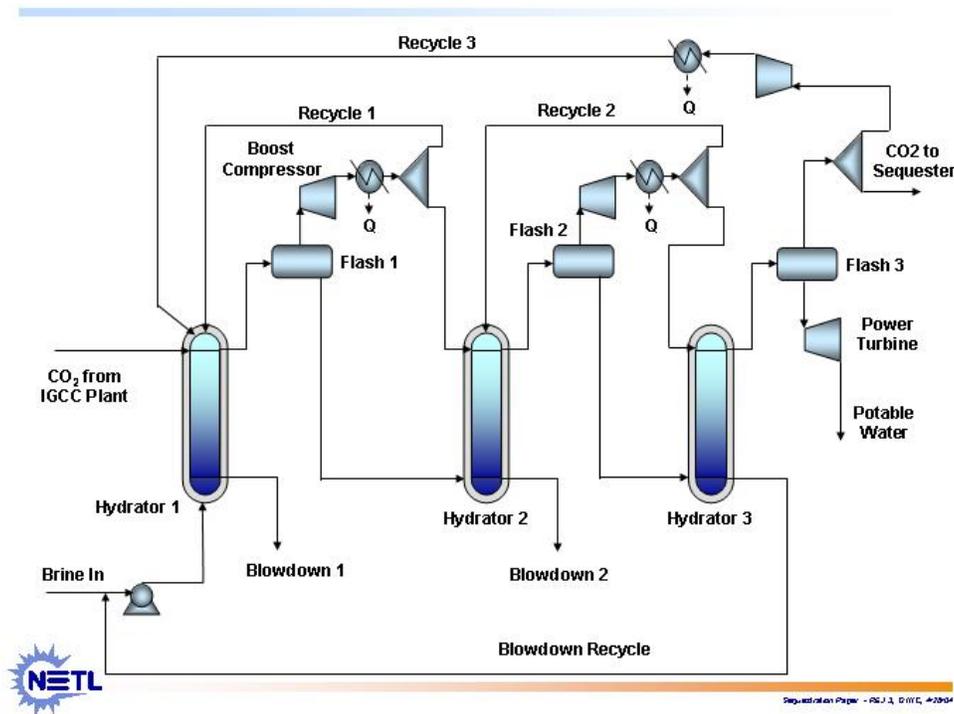


Figure 9. CO<sub>2</sub> hydrate-desalination process in an IGCC power plant systems perspective. Source: James and McGurl, 2004

*Draft*

<b>Gross/net CO<sub>2</sub> reduction per tonne of primary CO<sub>2</sub></b>	Does not directly reduce CO <sub>2</sub> via capture from an effluent stream that would be released to the atmosphere.
<b>Estimated scale of single application (i.e. plant size or field size)</b>	Economics of technology would determine minimum size of installation that would be feasible. Limited analysis focused on application at a 425 MW (nominal) IGCC unit.
<b>Estimated time to full deployment/ market saturation</b>	5 to 10 years depending upon whether an economic driver exists for this purpose.
<b>Estimated duration of significant impact</b>	Could be viable for the life of the facility to which it is attached.
<b>Special requirements on CO<sub>2</sub> (purity, etc.)</b>	Power plant, cement kiln flue gas
<b>Process/Technology Input Raw Materials and/or Energy</b>	Carbon dioxide, brine, seawater, electricity
<b>Process/Technology Outputs</b>	Potable water and a CO <sub>2</sub> sludge for disposal.
<b>Any concomitant advantages? (For example, Does this process eliminate the need for other pollution control equipment?)</b>	The process could produce plant process water and create potable water for sale at a lower cost compared to reverse osmosis systems.
<b>Value of carbon dioxide in this activity</b>	Carbon dioxide could have a value that approximates cost of materials (chemicals, etc.) used by competing treatment options.
<b>Legal/regulatory framework governing/impacting deployment of this option</b>	Water law could complicate distribution of produced water.

## 5.4 Carbon dioxide as a Working Fluid

### 5.4.1 Introduction

Aside from the potential consumptive uses for carbon dioxide and its potential for reuse in such applications as enhanced oil recovery, carbon dioxide can perform as a working fluid in a great number of applications:

- Coal cleaning<sup>64</sup> and injection of coal into gasifiers and combustors<sup>65</sup>
- Heat transfer fluid in power systems
  - Gen IV nuclear reactor studies<sup>66</sup>
  - Geothermal power studies<sup>67</sup>
  - More efficient heat transfer medium<sup>68</sup>
- Transport media in freight pipelines<sup>69</sup>
- Recovery of rare earth elements, treating hazardous waste via solvent extraction...see Actinide Separation Chemistry in Nuclear Waste Streams and Materials<sup>70</sup> and other similar (based on supercritical fluid properties) applications<sup>71</sup>.

In a few cases, the proposed use for carbon dioxide actually traps the CO<sub>2</sub> underground (see WO 2010/104599 A2) or may involve transforming some of the carbon dioxide into another form, perhaps as oxalates or carbonates (see the rare earth recovery patent).

These applications for carbon dioxide could form elements of a system that is designed to optimize the value derived from capturing large amounts of carbon dioxide. Ultimately, most of that captured CO<sub>2</sub> would be sequestered. However, on a region-by-region basis, many of the processes described in this summary could operate off a supply chain focused on a CO<sub>2</sub> pipeline network to produce value. How such economic benefits might be used to lessen the overall cost of capture and storage is not germane to the purpose of this document. If one sought to find useful things to do with carbon dioxide produced in energy conversion or other manufacturing processes to the greatest extent possible, constrained only by cost, energy consumption, and potential market size (see the section on metrics), these uses could be seen as bridges between sources and sinks or as opportunities that offset uses of other greenhouse gases with higher global warming potential (GWP). They would never justify capture nor increased use of a fossil fuel on their own. The concepts typically focus on the beneficial properties of supercritical carbon dioxide (scCO<sub>2</sub>).

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<sup>64</sup> See: Advanced Physical Coal Cleaning, CONF-940780, Vol. 1, Part 2 pages 67 – 74 (1994)

<sup>65</sup> J. Phillips, Program on Technology Innovation: Advanced Concepts in Slurry-Fed Low-Rank Coal Gasification – *Liquid CO<sub>2</sub>/Coal Slurries and Hot Water Drying*, Report #1014432, Technical Update, December 2006

<sup>66</sup> Chang H. Oh, Thomas Lillo, William Windes, Terry Totemeier, Bradley Ward, Richard Moore and Robert Barner, Development Of A Supercritical Carbon Dioxide Brayton Cycle: Improving VHTR Efficiency And Testing Material Compatibility - Final Report, INL/EXT-06-01271(March 2006) Idaho National Laboratory

<sup>67</sup> See, for example, WO 2010/104599 A2, International Patent Application PCT/US 2010/000756 (March 2010)

<sup>68</sup> See, for instance, (a) US Patent 3,971,211 (July 1976), (b) <http://www.echogen.com/products>

<sup>69</sup> See, for instance (a) US Patent 4,721, 420 (Jan 1988)

<sup>70</sup> NEA Nuclear Science Committee, Actinide Separation Chemistry in Nuclear Waste Streams and Materials, NEA/NSC/DOC(97)19

<sup>71</sup> Eric J. Beckman, Supercritical and near-critical CO<sub>2</sub> in green chemical synthesis and processing, J. of Supercritical Fluids 28 (2004) 121–191

To address this disparate collection of concepts, this section will start with coal cleaning and coal transport (including injection into combustion devices or gasifiers) then proceed through power cycles based on carbon dioxide, to long-distance freight pipelines based on scCO<sub>2</sub> as the carrier fluid to a host of smaller commercial applications such as solvent extraction.

#### 5.4.2 Coal Cleaning and Coal Transport

Among a number of proposed uses for carbon dioxide in coal cleaning, the liquid carbon dioxide (LICADO) process<sup>72</sup> has been the subject of significant R&D. The process was originally conceived as a separation technique when seeking deep levels of cleaning for finely-ground bituminous coals. The process relies on the relative “wettability” of clean coal and mineral matter to liquid carbon dioxide and water, respectively. Process development included conducting tests in a small-scale continuous unit that recycled the carbon dioxide. The CO<sub>2</sub> was flashed off of the coal and back to a gas then returned to the liquid state for reuse.

EPRI<sup>73</sup> issued a report in 2006: *Program on Technology Innovation: Advanced Concepts in Slurry-Fed Low-Rank Coal Gasification - Liquid CO<sub>2</sub>/Coal Slurries and Hot Water Drying (#1014432)*. In summarizing the work supported by EPRI and others, the author states:

“...to our knowledge, no other organization is currently looking at liquid CO<sub>2</sub>/coal slurries. During the 1980s EPRI sponsored several projects related to the concept of using liquid CO<sub>2</sub> as a slurring medium for pulverized coal. The most relevant of the earlier EPRI projects on liquid CO<sub>2</sub>/coal slurry was documented in EPRI AP-4849 in 1986. That project, conducted by Arthur D. Little, Inc., carried out laboratory and pilot plant scale tests on liquid CO<sub>2</sub> slurries...with up to 88wt% solids...

The results of AP-4849 were used in a subsequent engineering-economic study on the use of lignite in an IGCC [power cycle]. The study was documented in EPRI AP-4509, also published in 1986. The results indicated that the cold gas efficiency of the gasification process could be increased by 13 percentage points by using liquid CO<sub>2</sub>/lignite slurry...contemporary concerns about greenhouse gas emissions and their link to climate change has increased interest in capturing and storing CO<sub>2</sub> from future coal-based power plants. If CO<sub>2</sub> is going to be captured and compressed to greater than 2000 psi (14 MPa) for storage, then the incremental cost of producing liquid CO<sub>2</sub> for a coal slurry will be quite small... While the present analysis has cast doubts on the ability to actually achieve slurry solids contents as high as 88 wt%, the analysis does indicate there is sufficient promise in the concept to justify additional work...”

#### 5.4.3 Power Cycles

There is a rich history of papers and patents dealing with uses of carbon dioxide as a working fluid (heat transfer fluid). In particular, there have been numerous power cycles or power cycle improvements put forward using supercritical carbon dioxide. For instance, a power cycle was developed and patented by Ernest G. Feher (US patent 3,237,403 entitled “Supercritical Cycle Heat Engine”). Subsequent patents improving on the concept include US Patent 3,971,211 (issued in 1976) entitled Thermodynamic Cycles with Supercritical CO<sub>2</sub> Cycle Topping.

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<sup>72</sup> See (a) earlier citation #64...Klinzing, Chang, Morsi, etc. and (b) Advanced Coal Cleaning session

<sup>73</sup> EPRI

As part of the program to develop the Very High Temperature Gas Reactor (HTGR), a Gen IV nuclear system designed for high efficiency electricity generation and high temperature process heat applications, INL<sup>74</sup>, ANL<sup>75</sup>, and MIT<sup>76</sup> all explored the role that supercritical CO<sub>2</sub>-based Brayton cycles might play in this system. The HTGR and other Gen IV concepts included an indirect heat exchange between the internal heat exchanger within the reactor and an external cooling system. The working fluid for the external portion of the indirect heat exchanger was a subject of study and one of the options was to replace the standard steam Rankine cycle with a supercritical CO<sub>2</sub> Brayton cycle.

Multiple gases have been evaluated during the Gen IV program but several of the papers found an advantage when using supercritical carbon dioxide. The INL study found that the reduced volumetric flow rate of carbon dioxide due to higher density compared to helium will reduce compression work, which lowers turbine work losses, enhancing the plant net efficiency. Over a range of simulations, varying outlet temperatures and pressures, the CO<sub>2</sub> Brayton cycle typically showed the highest efficiency amongst the gases tested in the indirect configuration, reaching ~50.7%. This was two to four percentage points higher than with other gases in similar configurations. The supercritical CO<sub>2</sub> approach also suggested other simplifications and the use of smaller components representing a savings in capital cost. A number of other applications for supercritical carbon dioxide in heat transfer applications have been developed.

#### 5.4.3.1 Use of CO<sub>2</sub> in Enhanced Geothermal Energy Recovery Systems

Conventional geothermal energy systems require water as a working fluid. Heat is recovered using a steam turbine, which requires geothermal source temperatures above 185 °C. The drawbacks of this system include water losses, and the inability to use low-temperature geothermal sources. The use of CO<sub>2</sub> to overcome such limitations was first proposed in 2000. CO<sub>2</sub> sequestration and concomitant geothermal energy recovery are the twin features of this process. The U.S. DOE Office of Energy Efficiency and Renewable Energy (EERE) is currently funding multiple field- and laboratory-scale research and modeling studies aimed at better understanding of the behavior and impacts of CO<sub>2</sub> injection in geothermal reservoirs. These projects are addressed under the ‘*enhanced geothermal systems*’ and ‘*low-temperature and co-produced resources*’ program portfolios. Two field studies in Arizona and Texas are focused on CO<sub>2</sub>-enhanced geothermal electric power generation. GreenFire Energy’s CO<sub>2</sub>E<sup>TM</sup> suite of technologies will be field-tested at St. John’s Dome in eastern Arizona. Heat is recovered from CO<sub>2</sub> in a binary power generation cycle<sup>77</sup> (Figure 10A). Lawrence Berkeley National Laboratory (LBNL) and Echogen Power Systems plan to design, build and test a geothermal system with CO<sub>2</sub> as the working fluid operating on a high-efficiency supercritical CO<sub>2</sub> turboexpansion cycle<sup>78</sup> (Figure 10B). The magnitude of CO<sub>2</sub> use in this process depends on reservoir and wellbore flow properties, and CO<sub>2</sub> stored within the reservoir by mineralization, dissolution, or out-of-zone migration.

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<sup>74</sup> Chang, Oh, *Ibid.*, page 33

<sup>75</sup> Anton M. and James J. Sienicki, Argonne National Laboratory, Supercritical CO<sub>2</sub> Brayton cycle control strategy for autonomous liquid metal-cooled reactors, presented at The Americas Nuclear Energy Symposium, Miami Beach, Florida, October 3-6, 2004

<sup>76</sup> Hejzlar et al., Assessment of gas cooled fast reactor with indirect supercritical CO<sub>2</sub> cycle, *Nuclear Engineering and Technology*, v.38(2), Special Issue on ICAPP '05.

<sup>77</sup> EERE, 2011, Department of Energy Announces \$20 Million to Boost Development of Innovative Geothermal Technologies, Available at: [http://apps1.eere.energy.gov/news/progress\\_alerts.cfm/pa\\_id=401](http://apps1.eere.energy.gov/news/progress_alerts.cfm/pa_id=401), Accessed 9/28/2011.

<sup>78</sup> Krotz, D., 2011, Store CO<sub>2</sub> Underground and Extract Electricity? A Berkeley Lab-led Team is Working on it, Available at: <http://newscenter.lbl.gov/feature-stories/2011/08/08/geothermal-co2/>, Accessed 9/28/2011.

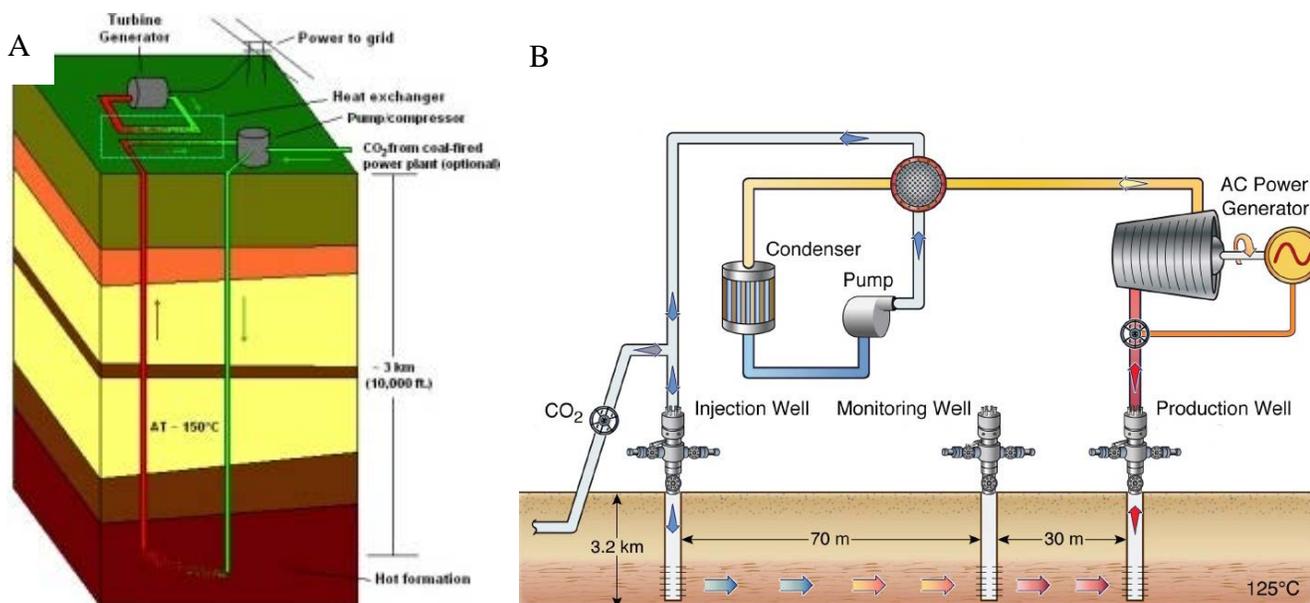


Figure 10(A): Schematic of the GreenFire geothermal system, (B): Illustration of the proposed LBNL/Cranfield field-scale geothermal power system test.

#### 5.4.4 Freight Pipelines

A significant body of literature exists on the concept of freight pipelines. The term captures a broad range of technologies including pipelines with automated rail systems based on electromagnetic/linear induction, slurry pipelines, and pneumatic (or gas-driven) systems. The Texas Transportation Institute at Texas A&M completed a study in 2003<sup>79</sup> that looked at freight pipeline systems for Texas. The report examined a number of options for freight pipeline systems hauling a variety of goods and commodities across the state. The benefits result directly from lower costs per ton-mile, lower energy consumption (and lower greenhouse gas emissions) and indirectly from reduced congestion on road that would otherwise bear increasing numbers of heavy trucks. The report favored pneumatic systems driven by high pressure gases (inert or air). The concept of using carbon dioxide in some form as a transport media in pipelines<sup>80</sup> has also been explored for bulk solids.

#### 5.4.5 Solvent Extraction

Supercritical carbon dioxide has been proposed as a sustainable solvent by a number of researchers and process developers. Beckman (2004)<sup>81</sup> reviewed the use of supercritical or near-critical carbon dioxide in chemical synthesis and processing. The focus of the article was to “uses of CO<sub>2</sub> that are relatively new and appear to provide ‘green’ advantages. It should be noted that there are examples provided in this paper where a CO<sub>2</sub>-

<sup>79</sup> Stephen S. Roop, et al., Texas Transportation Institute, Year 4 report on the technical and economic feasibility of a freight pipeline system in Texas, Report 9-1519-4, Sponsored by the Texas Department of Transportation In Cooperation with the U.S. Department of Transportation Federal Highway Administration October 2003

<sup>80</sup> See reference 6: US Patent 4,721, 420 (Jan 1988)

<sup>81</sup> Beckman, Ibid, page 121-122

based process is not particularly ‘green’, yet is generating interest because it produces better quality product than conventional alternatives.”

One area in which a substantial body of literature exists focuses on recovery of rare earth elements from various materials including nuclear wastes<sup>82</sup>. Current methodologies used for fuel reprocessing generate large amounts of low level waste. The use of scCO<sub>2</sub> would facilitate separation leaving concentrated residues that could then be more easily stored. The NEA Nuclear Science Committee published a report, Actinide Separation Chemistry in Nuclear Waste Streams and Materials<sup>83</sup>, a report of the NEA Nuclear Science Committee (NEA/NSC/DOC(97)19) which discussed the recovery of uranium, thorium, and various lanthanides through the use of scCO<sub>2</sub> in supercritical fluid extraction (SFE). Small amounts of chelating agents needed to be added to achieve satisfactory results. No specific tonnages were cited but stored waste from the nuclear industry is a significant issue even if quantities are modest (100,000’s of tons) compared to other applications. Mineral processing for lanthanides could also be a high-value use, because of the current market situation<sup>84</sup> is creating incentives for domestic development and recycling.

## 5.5 Fuels and Organic Chemicals from CO<sub>2</sub>

Fuels and organic chemicals are discussed together because the processes used to produce fuels and organic chemicals generally differ only slightly, if at all. This is also true for their production from CO<sub>2</sub>. The products form two categories; those that we burn are called fuels and those we use for other purposes are called chemicals.

To produce hydrocarbon fuels and organic chemicals from CO<sub>2</sub> requires that the combustion process be reversed and that oxidized carbon, in the form of CO<sub>2</sub>, be chemically reduced. This reduction is energy intensive and while the complete process is thermodynamically unfavorable, it does have merit. The value of the concept is that the products used for fuel are then carbon neutral, provided that the energy source for conversion is carbon neutral, e.g., hydrogen generated from nuclear, solar or other renewable energy sources. The net result is that non-fossil energy sources can be made portable by converting their energy to hydrocarbon fuels which use existing technologies and infrastructure. The conversion of CO<sub>2</sub> to organic chemicals results in a net-carbon emission reduction which is dependent on the lifetime of the products. For example, polymers would keep carbon in the reduced state longer than volatile compounds. It should be noted that any eventual oxidation of chemicals produced in this way would be carbon neutral. The net-benefits from converting CO<sub>2</sub> to fuels or chemicals strongly depend on the cost of hydrogen. Various studies indicate that hydrogen produced from steam methane reforming (SMR) or coal gasification is cheaper than that produced using renewable energy technologies such as solar photovoltaics, concentrated solar power (CSP), wind energy and biomass. Studies also indicate that CO<sub>2</sub> emissions from the production of hydrogen from coal or natural gas can be mitigated by geologic CCS, at costs of ~2.5 \$/kg for H<sub>2</sub> from SMR and 1.8 \$/kg for H<sub>2</sub> (2007 \$) from coal

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<sup>82</sup> Quintus Fernando, et al. , Formation of Rare Earth Carbonates Using Supercritical Carbon Dioxide, US Patent 5,045,289 (September 1991)

<sup>83</sup> NEA Nuclear Science Committee, Actinide Separation Chemistry in Nuclear Waste Streams and Materials, NEA/NSC/DOC(97)19

<sup>84</sup> Lee, J., 2009. China’s Ring of Power. Foreign Policy. Available at: [http://www.foreignpolicy.com/articles/2009/09/09/going\\_green](http://www.foreignpolicy.com/articles/2009/09/09/going_green) [Accessed September 29, 2011].

gasification (Bartels et al., 2010<sup>85</sup>). Bartels et al. also report that the near-term cost of hydrogen production using wind energy would be \$4 to \$5.5/kg H<sub>2</sub>. The higher value is consistent with electrolyzer power consumption of ~52 kWh/kg H<sub>2</sub> and levelized electricity costs of ~\$100/MWh. The EIA's annual energy outlook (AEO, 2011) projects that wind electricity, currently considered to be the most cost-effective among renewable energy technologies (excluding hydroelectric power) would have a levelized cost of ~97 \$/MWh (2009\$, by 2016)<sup>86</sup>. In comparison, the U.S. DOE goal for hydrogen cost is 2 to 3 \$/gge (ca. 2 to 3 \$/kg H<sub>2</sub> delivered, untaxed, 2005 \$, by 2015)<sup>87</sup>. This goal is independent of the pathway used to produce hydrogen. We used \$3.5/kg H<sub>2</sub> as the reference hydrogen price in this report. The costs of hydrogen vary with the scale of production and also vary geographically. For example, small-scale (100 kg/d) electrolysis production costs in the U.K. were estimated to be \$6 to \$16/kg H<sub>2</sub><sup>88</sup>.

Producing hydrocarbons from CO<sub>2</sub> also conserves petroleum while permitting continued use of the existing petroleum based infrastructure. This latter is important when considering the "hydrogen economy." If the hydrogen, as an energy carrier, is distributed as molecular hydrogen, replacement of the petroleum-based transportation infrastructure is estimated to be on the order of trillions of dollars with a complex transition phase. Chemically reducing CO<sub>2</sub> to hydrocarbons with hydrogen would use the carbon as a hydrogen shuttle and avoid the expense of infrastructure replacement while providing the high energy densities and ease of handling only afforded by liquid hydrocarbons. The technologies addressed by this section could be readily applied, in the future, to CO<sub>2</sub> captured from the atmosphere and recycled indefinitely as a hydrogen carrier in the form of hydrocarbon fuels.

There are many pathways to chemically reduce CO<sub>2</sub> to hydrocarbons by a chemical reducing agent, such as hydrogen or methane, by electrons in an electrochemical cell, or by photons in photocatalytic processes, such as photosynthesis in biological organisms. In all cases, the carbon would be reused at least once and the process would be carbon neutral, provided that the reductant was produced using non-fossil resources. Although full scale production would use non-fossil resources to reduce CO<sub>2</sub> to hydrocarbons, many of the experimental and developmental projects will use available materials and power for convenience.

### 5.5.1 Metrics: Conversion of CO<sub>2</sub> to fuels and organic chemicals

Nominal-net benefit analysis indicates that the conversion of CO<sub>2</sub> to fuels such as diesel, gasoline and methanol (~-200 \$/T) is less 'beneficial' than CO<sub>2</sub> to chemicals (formic acid, acrylic acid, plastics: ~750 to 2000 \$/T). However, the quantity of CO<sub>2</sub> which could be used to produce chemicals is small compared to amounts of CO<sub>2</sub> which could be used to make fuels. Both of these applications recycle carbon from fossil fuels.

Table 7 provides an overview of results for the options identified.

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<sup>85</sup> Bartels, Jeffrey R., Michael B. Pate, and Norman K. Olson. 2010, An economic survey of hydrogen production from conventional and alternative energy sources, *International Journal of Hydrogen Energy*, v.35 (16) (August), pp.8371-8384.

<sup>86</sup> [http://205.254.135.24/oiaf/aeo/electricity\\_generation.html](http://205.254.135.24/oiaf/aeo/electricity_generation.html)

<sup>87</sup> [http://www1.eere.energy.gov/hydrogenandfuelcells/news\\_cost\\_goal.html](http://www1.eere.energy.gov/hydrogenandfuelcells/news_cost_goal.html)

<sup>88</sup> <http://www.renewableenergyfocus.com/view/22045/itm-power-says-hfuel-hydrogen-costs-already-below-european-2015-target/>

Table 7. Fuels and Organic Chemicals from CO<sub>2</sub>

	CO <sub>2</sub> Mitigation			Benefits
	(A) CO <sub>2</sub> Reduced (total)	(B) Amount of CO <sub>2</sub> consumed (MT/y)	(C) CO <sub>2</sub> Capture in-built?	(D) Cost of CO <sub>2</sub> reduction (\$/T)
<b>Gasoline</b>	See (B)	1,229* (100%) See Appendix	No	247 \$/T CO <sub>2</sub> * See Appendix
<b>Distillate Fuel (diesel)</b>		416* (100%) See Appendix		237 \$/T CO <sub>2</sub> * See Appendix
<b>Methanol</b>		11* (100%) See Appendix		190 \$/T CO <sub>2</sub> * See Appendix
<b>Acrylic acid</b>		0.73* (100%) See Appendix		-1,988 \$/T* See Appendix
<b>Polyethylene carbonate (Plastics)</b>		2.5* See Appendix		-760 \$/T CO <sub>2</sub> * See Appendix
<b>Urea production</b>		101* (see Urea write-up for details)		-183 \$/T CO <sub>2</sub> See writeup
<b>Formic acid</b>		0.5 (globally, see writeup)		-1075 \$/T CO <sub>2</sub> * See Appendix
<b>Algal fuels</b>		2 T CO <sub>2</sub> /T dry algal biomass, 14 to 47 kg CO <sub>2</sub> /gal algal oil/biodiesel		May use pure CO <sub>2</sub> or flue gas (dilute CO <sub>2</sub> )

Values preceding asterisks are specific to the U.S.A

Market potential: A fraction of the value in (1.2) in the preceding table could be realistically supplied using CO<sub>2</sub> for each of the processes where CO<sub>2</sub> is converted to fuels and organic chemicals. CO<sub>2</sub> conversion to urea does not remove CO<sub>2</sub> from atmosphere, because urea is decomposed back to CO<sub>2</sub> when used as a fertilizer or a source of ammonia. Asterisks in table indicate U.S.-specific estimates. Life cycle analyses would be required to estimate energy consumption, energy penalty and CO<sub>2</sub> emissions from processes converting CO<sub>2</sub> to fuels and organic chemicals.

## 5.5.2 Fuels and Organic Chemicals by Chemical Process

### Introduction

The reduction of CO<sub>2</sub> in two electron increments produces first formic acid, then formaldehyde, then methanol, and finally methane. Methanol synthesis is a common industrial process that uses CO and hydrogen:



but the process can be run using the same catalyst with CO<sub>2</sub> as a feedstock



The synthesis of methanol from CO<sub>2</sub> may also involve indirect reduction. For example, the catalytic hydrogenation of organic carbonates, carbamates and formates under mild-temperature and pressure conditions to methanol has been recently demonstrated<sup>89</sup>. Such routes may be more cost-effective compared to direct hydrogenation of CO<sub>2</sub>. The production of organic carbonates from methanol and CO<sub>2</sub> and their subsequent hydrogenation results in net-methanol production. Other applications include the synthesis of organic carbonates from CO<sub>2</sub> and methanol under mild conditions, e.g. the Novomer process. The advantage of producing methanol is that the capital expenses are relatively low, the economy of scale does not handicap distributed production, and methanol is an important chemical commodity that can be used as a fuel in a high-compression internal combustion engine. The downside to methanol is that while it is a liquid fuel, it lacks the energy density of hydrocarbon fuels, has lower fuel economy than gasoline, and requires modifications to infrastructure and vehicular fuel and engine systems. Fortunately, methanol is readily converted to gasoline with high specificity by the ExxonMobil methanol-to-gasoline (MTG) process. Methanol can also be converted to diesel by the oligomerization and isomerization of ethylene, an important chemical intermediate produced by modifying the MTG process.

Alternatively, CO<sub>2</sub> can be reduced to CO and, with additional hydrogen, all reactions of synthesis gas (a mixture of carbon monoxide and hydrogen also known as syngas) become available including the Fischer-Tropsch (F-T) synthesis. This process is the most proven of the synthetic hydrocarbons processes and has a long history of development in South Africa by Sasol. Additionally, a broad suite of chemicals is available through syngas chemistry (Wender, 1996).

### 5.5.2.1 Algae-Based Fuels

Microalgae are photosynthetic microorganisms which convert CO<sub>2</sub>, water and light energy to algal biomass, typically at significantly higher productivities as compared to terrestrial plants<sup>90</sup>. Under certain conditions, genetically unmodified microalgae can store as much as 50% of their biomass in the form of oils such as lipids or triacylglycerols (TAGs) (Pienkos and Darzins, 2009; Wijffels and Barbosa, 2010). These oils are one of the precursors for fuels such as biodiesel, jet fuel and gasoline. Microalgae can be grown using non-arable lands and a wide variety of water sources which could lessen perceived food-fuel conflicts. This section is intended to be a review of the main features of algal biofuels and not a comprehensive, detailed review. The reader is

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<sup>89</sup> Balaraman, E. et al., 2011. Efficient hydrogenation of organic carbonates, carbamates and formates indicates alternative routes to methanol based on CO<sub>2</sub> and CO. *Nature Chemistry*, 3(8), pp.609-614.

<sup>90</sup> This discussion includes cyanobacteria (informally known as blue-green algae), which lack cell nuclei (prokaryotes) are therefore not formally classified with algae (eukaryotes). The term 'algae' refers to microalgae, as compared with macroalgae (sea weeds).

referred to pertinent scientific studies and systems analyses on algal biofuels (such as Pienkos and Darzins, 2009; Chisti, 2008; Beer et al., 2010; Greenwell et al., 2009, Lundquist et al., 2010) for further details.

The general steps involved in producing liquid fuels from algae are: species selection, culture and growth, nutrient and waste-stream management, oil extraction and processing to produce the desired fuel. The algal oil can be extracted from the microalgae and converted into biodiesel using alcohols (similar to soy biodiesel) or it may be used to produce linear hydrocarbons. Algae can also make hydrogen, ethanol and hydrocarbons resembling crude oil (Wijffels and Barbosa, 2010). The spent algal biomass could be used as animal feed, or converted to synthesis gas (syngas), the feedstock for a wide variety of chemicals and fuels via synthetic processes (Wender, 1996). Spent algal biomass may also be fermented in the absence of air to produce biogas with a high methane content, which could be readily upgraded to pipeline-quality natural gas. Other routes include integrated processing of algal biomass in a biorefinery producing a slate of valuable by-products and fuels, and the production of hydrocarbons and other fuels directly from genetically modified microorganisms such as cyanobacteria (e.g. Reppas and Ridley, 2010).

Microalgae may be cultivated in shallow open ponds, closed photobioreactor (PBR) systems, or hybrid designs. Open shallow ponds or raceway systems are less expensive and have lower algal biomass yields compared to engineered PBR systems. High-algal biomass and high-lipid content may be mutually exclusive (with genetically unmodified algae) (Sheehan et al., 1998). Two-stage, or hybrid designs aim to overcome this limitation. In hybrid designs, microbes are initially grown in closed photobioreactor systems under controlled conditions favoring cell growth, and minimal contamination before being transferred to open ponds or raceway systems (Huntley and Redalje, 2006). Such hybrid approaches may lead to reduced costs compared to photobioreactors alone. At least two algal biofuel companies (HR BioPetroleum, Sapphire Energy) currently adopt the hybrid approach to cultivate and harvest algae.

The extent to which algal biofuels may displace fossil-derived petroleum fuels and the amount of CO<sub>2</sub> recycled is shown in Table 8. Pienkos and Darzins (2002) note that the theoretical maximum algal productivity cannot exceed 100 grams.m<sup>-2</sup>.d<sup>-1</sup> (22,340 gal/acre/yr, assuming 50% w/w oil). The current U.S. EPA renewable fuels standard (RFS2) calls for 0.8 billion gallons/year of biodiesel in 2011<sup>91</sup>. Systems analyses indicate that at the current state of development, algal biofuels cannot supply this volume for the next 10 to 15 years (see Bartis and Van Bibber, 2011 and references therein). If algal biofuels could be successfully commercialized, these preliminary calculations indicate that 10 to 40 million tonnes of CO<sub>2</sub> could be utilized by the producing 0.8 billion gallons of biodiesel (2.2 million gallons/day) using microalgae. Analysis of life-cycle CO<sub>2</sub> emissions from fuel produced from algae fixation of CO<sub>2</sub> and solar reduction of CO<sub>2</sub> indicates that such processes are could have significantly lower lifecycle CO<sub>2</sub> emissions, resulting in a significant climate benefit (i.e. reduction in CO<sub>2</sub> emissions) compared to petroleum (Kreutz, 2010; Vasudevan et al., 2012)<sup>92,93</sup>.

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<sup>91</sup> <http://www.epa.gov/otaq/fuels/renewablefuels/420f10056.htm>

<sup>92</sup> Kreutz, T., 2011. Prospects for producing low carbon transportation fuels from captured CO<sub>2</sub> in a climate constrained world. *Energy Procedia*, 4(0), pp.2121-2128.

<sup>93</sup> Vasudevan, V. et al., 2012. Environmental performance of algal biofuel technology options. *Environ. Sci. Technol.*, 46(4), pp.2451–2459. Low-impact, nominal, and high-impact algal oil productivity values used in this article are 19.2 g oil/m<sup>2</sup>/d, 5 g oil/m<sup>2</sup>/d, and 2.25 g oil/m<sup>2</sup>/d, which are close to those used in Table 8 (multiplication of first two rows results in 25, 6.25, and 1.5 g TEG/m<sup>2</sup>/d for the high-, medium-, and low-biofuel productivity cases, respectively).

The most practical approach to integrate algal fuels with the existing infrastructure would be to subject the algal oils to the same refining steps as petroleum, either alone or as a mixture with petroleum. This would produce a fuel identical to petroleum derived fuels and eliminate separate processes and logistics chains for raw and transesterified oils. Further, by allowing a ready fit of the new fuel into existing infrastructure and eliminating the need for biofuel-specific engine modifications, the economics of use and marketability would be greatly enhanced.

The production of algal biofuels is limited by the availability of suitable land resource, access to CO<sub>2</sub> and water. Estimates of future algal biofuel production vary significantly. Lundquist et al. (2010) note that land, water and CO<sub>2</sub> limitations may restrict algal biofuel production to less than a couple of billion gallons per year<sup>94</sup>. A report from Pike Research notes that 60 million gallons of algal biofuels may be produced worldwide (~20 million gallons in North America, mainly in the U.S.A.) annually by 2020<sup>95</sup>. More optimistic assessments from the Algal Biomass Organization (ABO) indicate 6,000 million (6 billion) gallons of algal biofuels per year by 2022<sup>96</sup>. A recent summary of US efforts on algal biofuels is provided by Morello and Pate (2010)<sup>97</sup>. The amount of land area and CO<sub>2</sub> needed to meet the current RFS2 advanced biofuel requirement (considering only algal biodiesel) under various scenarios of algae productivity is shown in Table 8.

Table 8: Estimates of algal biofuel production and CO<sub>2</sub> utilization to meet a RFS biodiesel mandate of 0.8 billion gallons of biodiesel per year (<http://www.epa.gov/otaq/fuels/renewablefuels/420f10056.htm>)

Scenario	Low Biofuel Productivity	Medium Biofuel Productivity	High Biofuel Productivity
<b>Productivity, g biomass/(m<sup>2</sup>.d)</b> See <sup>98</sup>	10	25	50
<b>% TAG</b>	15%	25%	50%
<b>gal/acre</b> See	633	2,637	10,549
<b>Million acres needed to produce 0.8 billion gallons/year*</b>	1.26*	0.30*	0.076*
<b>CO<sub>2</sub> used, MT/y</b> (@ 2 g CO <sub>2</sub> /g algal biomass)	37*	22*	11*

Values preceding asterisks are specific to the United States.

<sup>94</sup> Lundquist, T.J. et al., 2010. A realistic technology and engineering assessment of algae biofuel production, Energy Biosciences Institute. Available at: [http://digitalcommons.calpoly.edu/cenv\\_fac/188](http://digitalcommons.calpoly.edu/cenv_fac/188) [Accessed February 2, 2011].

<sup>95</sup> Lawrence, M. & Wheelock, C., 2010. Algae-Based Biofuels - Demand Drivers, Policy Issues, Emerging Technologies, Key Industry Players, and Global Market Forecasts. Executive summary available at: <http://www.pikeresearch.com/research/algae-based-biofuels> [Accessed February 2, 2011].

<sup>96</sup> Algal Biomass Organization, 2011. Algae biofuels edge closer to commercialization. Available at: <http://www.algalbiomass.org/news/2064/algae-biofuels-edge-closer-to-commercialisation/> [Accessed February 2, 2011].

<sup>97</sup> Morello, J. & Pate, R., 2010. The promise and challenge of algae as renewable source of biofuels. Available at: [www1.eere.energy.gov/biomass/pdfs/algae\\_webinar.pdf](http://www1.eere.energy.gov/biomass/pdfs/algae_webinar.pdf) [Accessed February 3, 2011].

<sup>98</sup> Data from Pienkos and Darzins (2009).



Figure 11: Photobioreactors and raceway systems for microalgae cultivation. (A, B): Flat-panel photobioreactors from Proviron, Belgium and Solix Biofuels, USA.(C): Open large-scale algae culture ponds, Nature Beta Technologies Ltd., Eilat, Israel.  
Source: Greenwell et al., 2009; Wijffels and Barbosa, 2010.

5.5.2.2 Algal Biofuels Process Factsheet

<b>Estimated impact /Net CO<sub>2</sub> considered permanently sequestered (US, MT CO<sub>2</sub>/yr)</b>	Replacement of 0.8* billion gal/yr of biodiesel results in the use of 11* to 40* MT CO <sub>2</sub> /yr (gross), depending on algal productivity
<b>Gross current (equivalent) CO<sub>2</sub> consumption in this use (US), million MT/year</b>	Zero
<b>Projected growth in future CO<sub>2</sub> demand for this application</b>	TBD
<b>Game-changing events/scenarios favorable for this process</b>	Less expensive algal biomass growth and processing, addressing contamination issues with genetically modified strains, higher algal productivity, better use of by-products

Values preceding asterisks are specific to the U.S.A

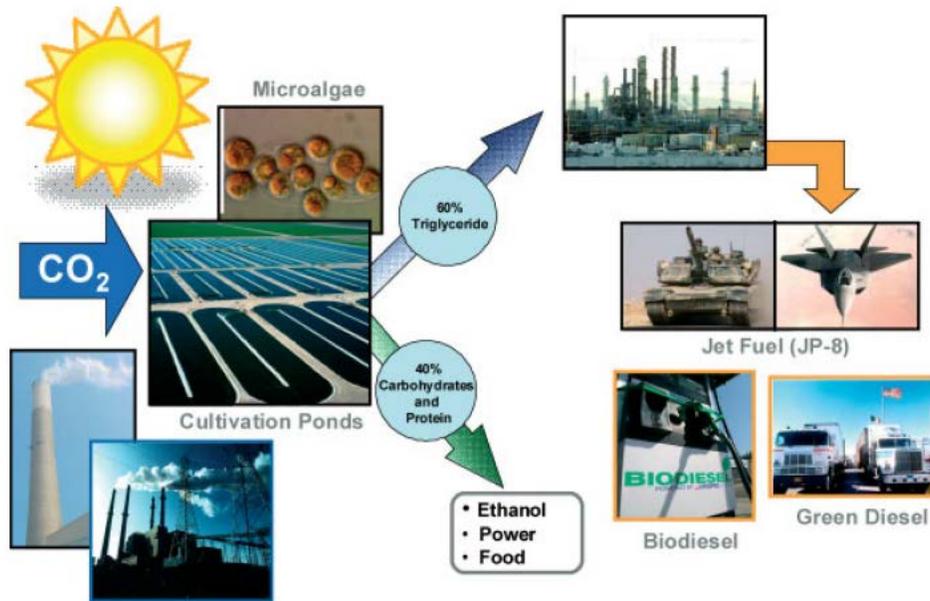


Figure 12. Algal biomass product streams. Source: Pienkos and Darzins, 2009.

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<b>Gross/net CO<sub>2</sub> reduction per tonne of primary CO<sub>2</sub> (<i>mention basis</i>)</b>	Estimates of CO <sub>2</sub> mitigation require a full life cycle analysis
<b>Indirect carbon dioxide impacts (tonnes per tonne)</b>	The fossil energy ratio ( $E^{\text{algal biofuel produced}}/E^{\text{fossil fuel spent}}$ ) of algal biofuels is claimed to be between 3.3 and 7.5 (Chisti, 2009)
<b>Estimated scale of single application (i.e. plant size or field size)</b>	TBD. Depends on light, water, land, CO <sub>2</sub> availability, and temperature. A 100 ha facility may require up to 50 TPD (100%) CO <sub>2</sub> , or equivalent amount of flue gas
<b>Number of deployments at maturity</b>	TBD
<b>Estimated time to full deployment/market saturation</b>	Analyses estimate a time period of 10 to 15 years for full commercialization
<b>Estimated duration of significant impact</b>	Can have a significant impact through the lifetime of the facility because the demand for high energy density liquid fuels would only increase in the future
<b>Cumulative reduction through 2050</b>	TBD. A life cycle analysis would determine CO <sub>2</sub> , and other GHG emissions avoided.
<b>Special requirements on CO<sub>2</sub> (purity, etc.)</b>	Flue gas streams may be used for algal biofuel production after SO <sub>x</sub> removal
<b>Process/Technology Input Raw Materials and/or Energy</b>	CO <sub>2</sub> stream, electrical energy required for operation, nutrients (nitrogen, phosphorus fertilizers), water, sunlight and the availability of land area
<b>Process/Technology Outputs</b>	Algal fuel, spent biomass/methane, water
<b>Any concomitant advantages?</b>	Generates biofuels
<b>Typical costs to deploy (state basis)</b>	TBD. Cost estimates vary by region, algae strain and the exact cultivation methods used. A 100 ha high-rate pond facility which also treats wastewater may cost from 35 to 50 million \$ (Lundquist et al., 2010).
<b>Value of carbon dioxide in this activity</b>	TBD. Site- and algal strain-specific life cycle analyses are required to estimate the net benefits. The costs of algal biofuels vary significantly among various analyses.
<b>Legal/regulatory framework governing use of this option</b>	Any future algal biofuel tax credit (currently none). EPA includes algal biofuels as ‘advanced biofuels’ in the renewable fuels standard

### 5.5.2.3 Chemicals

CO<sub>2</sub> can be used to produce chemicals such as urea, polycarbonates and acrylic acid-derivatives.

#### *Acrylates*

Acrylates are the salts and esters of acrylic acid. Polymers produced from acrylates are called polyacrylates. The various uses of acrylic acid and its derivatives include<sup>99</sup>:

1. Water-based acrylics: Used in decorative, masonry and industrial coatings.
2. Polyacrylates: Used as thickeners, dispersants and for rheology control applications.
3. Superabsorbent polymers (SAP): Superabsorbent polymers (SAP) are cross-linked polyacrylates with the ability to absorb and retain more than 100 times their own weight in liquid. SAPs are used in baby diapers and as soaker pads for packaging poultry, meat, fish and vegetables.
4. Detergent polymers (homopolymer polyacrylates and copolymers of acrylic acid and maleic anhydride): Used with both zeolites and phosphates in washing powder formulations.

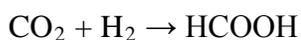
#### *Polycarbonates*

Polycarbonates are polymers containing organic carbonate (-O-(C=O)-O-) groups. One example of the use of CO<sub>2</sub> to produce plastics is the production of polyethylene carbonate (PEC) from ethylene oxide (EtO) and CO<sub>2</sub>. PEC is used as an oxygen barrier layer for food applications. The key innovations here include the development of catalysts which make the production of organic carbonates feasible under mild-temperature and pressure conditions. For example, Novomer is currently commercializing a process to produce PEC from CO<sub>2</sub> and ethylene oxide. Additionally, Bayer has been operating operating a kilogram-scale pilot plant since 2011, at Chempark Leverkusen, Germany, which uses CO<sub>2</sub> from a RWE lignite-fired power plant in Niederaußem, near Cologne, to produce polyether polycarbonate-polyols (PPP) used for the production of the high-grade plastic polyurethane. Industrial production is scheduled to begin in 2015<sup>100</sup>.

The benefits of using PEC instead of conventional barrier resins include a lower environmental footprint, and the capability to recycle CO<sub>2</sub>. PEC barrier layers can be integrated into traditional packaging plastics to enhance food storage and shelf life characteristics.

#### *Formic acid*

The synthesis of formic acid may be represented as:



As with all the CO<sub>2</sub>-to-chemicals applications, the source of hydrogen is assumed to be carbon neutral or renewable energy. The synthesis of formic acid may involve direct-CO<sub>2</sub> reduction by hydrogen gas, or indirect electrochemical reduction of aqueous carbonates or dissolved CO<sub>2</sub>. Processes such as the Mantra electrochemical reduction of carbon dioxide (ERC) belong to the latter category<sup>101</sup>. The nominal-net benefit of

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<sup>99</sup> <http://www.icis.com/v2/chemicals/9074870/acrylic-acid/uses.html>

<sup>100</sup> <http://www.press.bayer.com/baynews/baynews.nsf/ID/2012-0060-e>

<sup>101</sup> Oloman, C. & Li, H., 2007. Continuous Co-current Electrochemical Reduction of Carbon Dioxide. WO 2007/041872 A1. Available at: <http://www.wipo.int/patentscope/search/en/WO2007041872> [Accessed July 27, 2011].

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formic acid production from CO<sub>2</sub> and H<sub>2</sub> is calculated to be approximately \$1075/T CO<sub>2</sub>\*<sup>102</sup>. Det Norske Veritas (DNV) recently demonstrated the small-scale electrochemical reduction of CO<sub>2</sub> to formic acid and formate salts<sup>103</sup>, which adopts a different methodology to estimate CO<sub>2</sub> costs. The cost of CO<sub>2</sub> (\$ 220/T in the DNV study) is listed as a benefit, and the energy cost in the DNV analysis is estimated to be ~420 \$/T formic acid, compared to ~166 \$/T formic acid in the current analysis. With these estimates, the DNV analysis estimates a net nominal benefit of ~\$ 980/T HCOOH, or ~\$937/T CO<sub>2</sub>.

Global production of formic acid was 498,000 T in 2007, with 25,000 T produced in the USA<sup>104</sup>. This represents a CO<sub>2</sub> market of 476350 T/yr or ~0.5 MT/yr CO<sub>2</sub> globally and 0.024 MT/yr CO<sub>2</sub> in the USA. New applications such as hydrogen storage, fuel cells, oil-well completion and airport runway deicing, could increase the demand for formic acid.

### Urea production

The synthesis of urea from ammonia and carbon dioxide is a mature process compared to PEC, acrylate and biofuel production. Ammonia and CO<sub>2</sub> are reacted to form ammonium carbamate which is further dehydrated to form carbamide (urea) H<sub>2</sub>N-(C=O)-NH<sub>2</sub>. Note that ammonia itself is produced by the Haber process from hydrogen (produced by steam reforming of natural gas, or by water gas shift reactions of syngas derived from coal/petcoke gasification) and nitrogen (from cryogenic air separation). Global urea production in 2009 was 147.3 MT, leading to a CO<sub>2</sub> consumption of 109 MT<sup>105</sup>. Urea production in East Asia (including China) was 65.4 MT in 2009. North American urea production in 2009 was 9.7 MT. The annual rate of global growth (averaged for the past seven years) in urea production was 3.3%, compared to -2.3% decline in North American urea production. Global urea production in 2010 was estimated to be 149 MT (Heffer and Prud'homme, 2010)<sup>106</sup>.



Nominal-net benefit: 183\* \$/T CO<sub>2</sub><sup>107</sup>

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<sup>102</sup> 44 T CO<sub>2</sub> requires 2 T H<sub>2</sub> and produces 46 T formic acid. 1 T CO<sub>2</sub> = 1/22 T H<sub>2</sub> = 1/22\*3500 \$ H<sub>2</sub> cost = \$159/T CO<sub>2</sub>. 1 T CO<sub>2</sub> = 46/44 T HCOOH. Formic acid costs are ~1220 \$/T (see Sridhar and Hill, 2011) = 1275 \$/T CO<sub>2</sub>. Net benefit = 1275 – 159 – 40 ~ 1075 \$/T CO<sub>2</sub>.

<sup>103</sup> Sridhar, N. & Hill, D., 2011. Carbon Dioxide Utilization, Electrochemical Conversion of CO<sub>2</sub> – Opportunities and Challenges, Research and Innovation position paper, 07-2011, Available at: [http://www.dnv.com/binaries/DNV-position\\_paper\\_CO2\\_Utilization\\_tcm4-445820.pdf](http://www.dnv.com/binaries/DNV-position_paper_CO2_Utilization_tcm4-445820.pdf). [Accessed 31 March, 2011]

<sup>104</sup> Dunia Frontier Consultants, 2008. Dunia formic acid survey, <http://www.dfcinternational.com/files/DuniaFormicAcidSurvey15June2008.pdf>, [Accessed 31 March, 2011]

<sup>105</sup> [http://www.fertilizer.org/ifa/content/download/7858/122024/version/5/file/2009\\_urea\\_public.xls](http://www.fertilizer.org/ifa/content/download/7858/122024/version/5/file/2009_urea_public.xls)

<sup>106</sup> [http://www.fertilizer.org/ifacontent/download/48774/709486/version/1/file/2010\\_council\\_newdelhi\\_ifa\\_outlook.pdf](http://www.fertilizer.org/ifacontent/download/48774/709486/version/1/file/2010_council_newdelhi_ifa_outlook.pdf)

<sup>107</sup> 44 T CO<sub>2</sub> requires 34 T NH<sub>3</sub> and produces 60 T urea and 18 T water. Ammonia and urea U.S. CFR prices: [470 \\$/T](#) and [430 \\$/T](#) from ICIS. CO<sub>2</sub> price: 40 \$/T. 1 T CO<sub>2</sub> = 34/44 T NH<sub>3</sub> = 60/44 T urea. Raw material costs: 40 + 34/44x470 = 403 \$/T CO<sub>2</sub>. Urea cost: 430x60/44 = 586 \$/T CO<sub>2</sub>. Nominal-net benefit = 586-403 = 183 \$/T CO<sub>2</sub> (negative cost).

*Co-utilization of CO<sub>2</sub> and CH<sub>4</sub> to produce chemicals*

1. The source of hydrogen for the CO<sub>2</sub>-to-chemicals conversion processes discussed is natural gas, or some form of renewable energy. The co-utilization of CO<sub>2</sub> and CH<sub>4</sub> offers the prospect of using methane directly to produce valuable chemicals. Recent developments in shale gas plays have added production and gas reserves to the U.S. natural gas market. In its 'reference case' scenario, the EIA Annual Energy Outlook, 2011 (AEO2011) projects that shale gas would account for 47% of the U.S. natural gas production by 2035. The co-utilization of CO<sub>2</sub> and methane enables the use of two relatively inert gases and produces synthesis gas which can be used to produce chemicals such as methanol. The various routes to use CO<sub>2</sub> and CH<sub>4</sub> are: Tri-reforming of flue gas CO<sub>2</sub> with CH<sub>4</sub> and steam to produce syngas for F-T synthesis (Minutillo & Perna, 2009, 2010)<sup>108,109</sup>.
2. Use of methane as an anode fuel in fuel cells (e.g., FuelCell Energy's direct fuel cell [DFC]<sup>110</sup>) to convert flue gas and fuel to hydrogen and power.
3. Dry reforming of methane with CO<sub>2</sub> and processing the resultant syngas to obtain a CO:H<sub>2</sub> ratio favorable for chemical synthesis (1:2 for methanol) using the reverse water-gas shift reaction. A startup company, Carbon Sciences, Inc. plans to use dry reforming of methane using CO<sub>2</sub> to produce syngas for making fuels<sup>111</sup>. It is claimed that the overall process is close to carbon-neutral and has a low-steam usage, indicating a possible advantage of this process over conventional Fischer-Tropsch synthesis using steam methane reforming.
4. Stepwise production of ethylene (C<sub>2</sub>H<sub>4</sub>) using oxidative coupling of methane (e.g., Siluria process<sup>112</sup>) and subsequent production of plastics (polyethylene carbonates) and other chemicals (acrylic acid) using pure (i.e. separated) CO<sub>2</sub>.

The quantities of CO<sub>2</sub> and natural gas that could be used in the above processes is subject to further technology development.

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<sup>108</sup> Minutillo, M. & Perna, A., 2009. A novel approach for treatment of CO<sub>2</sub> from fossil fired power plants, Part A: The integrated systems ITRPP. *International Journal of Hydrogen Energy*, 34(9), pp.4014-4020.

<sup>109</sup> Minutillo, M. & Perna, A., 2010. A novel approach for treatment of CO<sub>2</sub> from fossil fired power plants. Part B: The energy suitability of integrated tri-reforming power plants (ITRPPs) for methanol production. *International Journal of Hydrogen Energy*, 35(13), pp.7012-7020.

<sup>110</sup> NETL, 2004, Combining power generation and carbon sequestration using a Direct FuelCell®, Available at: [www.netl.doe.gov/publications/factsheets/project/Proj319.pdf](http://www.netl.doe.gov/publications/factsheets/project/Proj319.pdf), [Accessed 10/31/2011].

<sup>111</sup> <http://www.carbonsciences.com/technology.html>, [Accessed: 10/31/2011].

<sup>112</sup> <http://siluria.com/Technology/Process>, [Accessed: 10/31/2011].

## 6 Consumptive Options

These applications involve the formation of minerals, or long-lived compounds from CO<sub>2</sub> leading to net-carbon sequestration by ‘locking-up’ carbon.

### 6.1 Consumptive Uses (Carbonation): Introduction

The conversion of CO<sub>2</sub> to mineral carbonates occurs naturally in the environment, but is exceedingly slow, and does not comprise an effective mitigation or a beneficial use of CO<sub>2</sub>. On the other hand, reactions leading to the formation of mineral carbonates are well understood. For the purposes of this document, the term carbonation refers to the conversion of CO<sub>2</sub> to mineral carbonates. This process requires “alkalinity” (i.e. base capacity) and water. Because magnesium and calcium form more stable carbonates, abundant magnesium- and calcium-silicate minerals (such as serpentine and olivine) have been a focus of previous research on aqueous/non-aqueous carbonation<sup>113,114</sup>. Such processes are energy-intensive, require additional alkalinity (i.e. sodium carbonate or sodium hydroxide addition) and require considerable investment in new plant infrastructure, resulting in high costs per ton of CO<sub>2</sub> converted to carbonate.

Whereas previous research into mineral carbonation assumed the use of high-purity CO<sub>2</sub>, current research efforts also include the use of flue gas CO<sub>2</sub> (10-15%). The use of enzymes such as carbonic anhydrase, which catalyze the hydration of CO<sub>2</sub>, may enhance carbonation rates. As an example, the use of such enzymes to improve the rates of carbonation of waste metal oxides from bauxite ore processing is being studied by Alcoa. The use of additional alkalinity generated by electrolysis of brines or saltwater to form alkali and alkaline-earth metal carbonates is being investigated by Skyonic and Calera. A process to cure precast concrete products in the presence of humid CO<sub>2</sub> is being developed by McGill University using the solvent technology of 3H Company to capture CO<sub>2</sub>. Finally, a process for carbonation of slag from steelmaking and the production of magnesium-based supplementary cementitious materials (Novacem) are also discussed. The primary benefits from the consumptive uses are comprised of avoided-CO<sub>2</sub> emissions (use of mineral carbonates, and various by-products such as hydrogen, chlorine and aggregate), and the sale of the mineral carbonates and by-products. These process-specific factsheets are included in the Appendix. A summary of various carbonation processes is presented in Table 12.

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<sup>113</sup> Metz, B. et al. eds., 2005. IPCC, 2005: IPCC Special Report on Carbon Dioxide Capture and Storage, Chapter 7. Prepared by Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, 442pp and references therein.

<sup>114</sup> O’Connor, W.K., D.C. Dahlin, G.E. Rush, S.J. Gledermann, L.R. Penner, D.N. Nilsen, 2005. Aqueous mineral carbonation, Final Report, DOE/ARC-TR-04-002.

## 6.2 Metrics

Table 11. Consumptive Uses, Carbonation

Carbonation Process	CO <sub>2</sub> Mitigation		Benefits	Energy Consumption			Market Potential		Benefit * Market Size, billion \$/y
	(A) Amount of Captured CO <sub>2</sub> utilized	(B) CO <sub>2</sub> Capture in-built?		(C) Value of by-products (\$/T CO <sub>2</sub> )	(D) Energy required for capture and disposal	(E) Energy penalty/gain for by-product process	(F) CO <sub>2</sub> emissions avoided	(G) Market Size	
<b>Skyonic</b>	Cl <sub>2</sub> : 14* MT/y Na <sub>2</sub> CO <sub>3</sub> : 20 MT/y H <sub>2</sub> : 836* MT/y <sup>115</sup> Algal biofuels: 578* MT/y, 4842 MT/yr (global -direct) <sup>[ Total Available Markets ]</sup>	Yes	Na <sub>2</sub> CO <sub>3</sub> : ~\$300/T, H <sub>2</sub> : ~\$10/T Cl <sub>2</sub> : ~\$240/T	1.456 MWh/T <sup>(NG-fired gen)</sup>	20%	2.91 T CO <sub>2</sub> /T CO <sub>2</sub>	See (A). A fraction of this could be supplied	Direct: Displaces natural Na <sub>2</sub> CO <sub>3</sub> or CaCO <sub>3</sub> used in Solvay process	3.4* to 9* <sup>116</sup>
<b>Alcoa</b>	2* to 23* MT/y	Yes	\$10 to \$300/T	NA	NA	NA		NA	~500* <sup>117</sup>
<b>Calera</b>	1500 MT/y sand and aggregate market: 3 billion T U.S. cement (20% share): 24 MT/y (of SCM w/ 50% w/w CO <sub>2</sub> )	Yes	Aggregate: \$7/T (i.e. \$14/T CO <sub>2</sub> overall) \$100/T cement	0.08 to 0.28 T CO <sub>2</sub> emitted/T CO <sub>2</sub> captured	8 to 28%	0.5 T CO <sub>2</sub> /T CO <sub>2</sub>		Displaces CaCO <sub>3</sub> for cement, replaces aggregate	21* <sup>118</sup>
<b>Concrete Carbonation</b>	2 to 8 million T/y*	No		0.2 T CO <sub>2</sub> emitted/T CO <sub>2</sub> converted	See (D)	NA		NA	TBD

<sup>115</sup> Large quantities of hydrogen and algal biofuels would require tremendous infrastructure investments on top of the investment in CO<sub>2</sub> infrastructure.

<sup>116</sup> U.S. Cl<sub>2</sub>: [240x14] 3.4 billion \$/yr. Global Na<sub>2</sub>CO<sub>3</sub>: (20x300) 6 billion \$/yr. U.S. H<sub>2</sub> (replacing NG): 836x10 ~8.4 billion \$/yr

<sup>117</sup> Potentially in the 10s of MT CO<sub>2</sub>/yr x 50 \$/T CO<sub>2</sub> range

<sup>118</sup> U.S. aggregate market: 1.5x14 = 21 billion \$/yr, U.S. Portland cement market: 24/0.5x100 = ~5 billion \$/yr

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Carbonation Process	CO <sub>2</sub> Mitigation		Benefits	Energy Consumption			Market Potential		Benefit * Market Size, billion \$/y
	(A) Amount of Captured CO <sub>2</sub> utilized	(B) CO <sub>2</sub> Capture in-built?	(C) Value of by-products (\$/T CO <sub>2</sub> )	(D) Energy required for capture and disposal	(E) Energy penalty/gain for by-product process	(F) CO <sub>2</sub> emissions avoided	(G) Market Size	(F) CO <sub>2</sub> subjected to capture & storage	
<b>Slag Carbonation</b>	7 to 18 MT/y, 0.5* to 1.3* MT/y	Currently no, possible	NA	0.14 T CO <sub>2</sub> w/ gridding slag/T CO <sub>2</sub> captured	NA		See (A). A fraction of this could be supplied	NA	TBD
<b>Novacem</b>	2130 MT/y <sup>(100% market share)</sup> , 54* MT/y	No	Cement: \$100/T cement blended	TBD					
<b>Cambridge Carbon Capture</b>	50 to ~1000 MT/y	Yes	NA						
<b>Calix</b>	2* to 23* MT/y	Yes	Cement fertilizer		Claimed 17% for syngas and ~7% for natural gas				

Various consumptive uses, or applications where CO<sub>2</sub> is converted into products with a long-life, form the basis for the third category of CO<sub>2</sub> uses. Several processes currently being developed to convert CO<sub>2</sub> to sodium or calcium/magnesium carbonates/bicarbonates were evaluated. In general, consumptive uses may have the potential to use or mitigate large quantities (billions of tonnes per year globally) of CO<sub>2</sub>. However, larger scale demonstration pilots are needed to evaluate their feasibility. In addition to mineral carbonates, other by-products from consumptive-use processes include chlorine, hydrogen, soil amendments, fertilizers, and building materials. Nominal-net benefits from consumptive uses vary from \$10 to \$300/T CO<sub>2</sub> depending on the product.

Table 12: An Overview of Various Carbonation Processes

	<b>Processes converting CO<sub>2</sub> to sodium carbonates (Na<sub>2</sub>CO<sub>3</sub>, NaHCO<sub>3</sub>)</b>	<b>Processes converting CO<sub>2</sub> to calcium and magnesium carbonates</b>		
<b>Source of base capacity</b>	NaOH produced by electrolysis of brine	Brine electrolysis, fly ash, alkaline waste, metal silicates, calcinations of dolomite	Calcium silicate hydrolysis producing lime	Fly ash, bauxite processing waste (red mud)
<b>Inputs</b>	Brine, CO <sub>2</sub> from flue gas	Brine, alkaline waste, dolomite, fly ash, metal silicates, CO <sub>2</sub> from flue gas, hydrocarbons	Pure, high-pressure CO <sub>2</sub> , concrete, water	CO <sub>2</sub> in flue gas, alkaline waste, fly ash, water
<b>Products</b>	Baking soda, soda ash, hydrogen, chlorine	Mixture of hydrated calcium and magnesium carbonates, calcium and magnesium oxides; carbonated silicate mineral, silica, electrical energy, fresh water	‘Cured’ concrete blocks (surface layer of calcium carbonate)	Mixture of sodium, calcium and magnesium carbonates, and other minerals including silica
<b>Primary product use</b>	Glass manufacture, source of CO <sub>2</sub> for microalgae cultivation, bleach, fuel	Cementitious material to blend with Portland cement, or for use as a custom binder material, or as aggregate, or a soil amendment	Precast concrete industry	Soil amendment, fertilizer
<b>Projected growth in future CO<sub>2</sub> demand</b>	Soda ash global demand: 1.5 to 2%, hydrogen demand growth may exceed that of soda ash	U.S. cement/aggregate: 1.1% to 1.6% World cement demand: 5% to 6%		Aluminum production grew at 5% per year historically (U.S.)
<b>Value of product</b>	\$10* to \$300* /T CO <sub>2</sub>	10 to 300 \$/T product	TBD	TBD, soil remediation products are priced similar to limestone
<b>Time duration of significant impact</b>	5 to 20 years depending on the economic incentives for each particular application			

## 7 Conclusions

This summary presents a survey of an emerging area of practical interest – the reuse and consumption of carbon dioxide. Although this has long been viewed as an attractive concept, most assessments have not found beneficial uses for carbon dioxide anywhere close to the scale of anthropogenic emissions of this greenhouse gas and therefore have suggested maintaining primary focus on large-scale capture and geologic storage. However, careful review of the full range of beneficial uses suggests that the contribution of these approaches might serve to both jump-start development of the infrastructure needed to manage large amounts of captured carbon dioxide (the chicken-and-egg problem) and to lessen the total social cost from this activity. Some of the beneficial use processes may fall under the purview of different environmental regulations compared to geologic CO<sub>2</sub> storage because they avoid the need for subsurface disposal (e.g., Calera or Skyonic processes). Comprehensive environmental assessments of all beneficial use processes are required to evaluate impacts on site permitting, operator liabilities, and facility operations.

Development of this document started with a review of previous work and an attempt to establish metrics that bridged across the wide range of uses for carbon dioxide – some that consume the carbon dioxide forming new chemical compounds, some that simply raise the useful energy extracted from the carbon-containing fuel that was reacted to form carbon dioxide, while leaving the CO<sub>2</sub> molecule in its original form (before being stored via sequestration), and another collection of ideas that would both tie the pieces of a carbon dioxide infrastructure together and perhaps improve the overall energetic efficiency of the carbon-based energy system. Primary considerations in establishing these metrics were:

- Total amount of CO<sub>2</sub> permanently sequestered
- Unit value (benefit) or cost of application
- Energy consumed by the application (or net-CO<sub>2</sub> savings from the technology)
- Market Potential of primary CO<sub>2</sub> use and any by-products

This summary has sought to discuss general categories of each of these aspects and to provide more significant detail on individual processes or pathways under the major headings. Where available, data on the potential market size and benchmark numbers for the value of any by-products or the energy benefits of a process are reported on a basis to allow comparisons. In the course of this study, certain technologies claimed to be competitive with geologic CCS. Some of the factors contributing to uncertainties in the costs and efficiencies of beneficial-use processes include:

1. Lack of operational experience with some technologies, and technology scalability issues, impacting capital and operational cost estimates,
2. Uncertain market incentives or costs for the end products,
3. The need for infrastructure and/or raw materials to capture or transport CO<sub>2</sub> on a large scale,

Several major conclusions become apparent:

1. No single application is capable of consuming major fractions of current or projected CO<sub>2</sub> emissions. This conclusion is certainly not new and has been stated by others in past assessments. Over the next several decades, large potential beneficial impacts (\$/T CO<sub>2</sub>eq) could be realized by the use of CO<sub>2</sub> to produce sources of raw material, fuels or chemicals. Hydrocarbon resource extraction (specifically, EOR) using advanced technologies could potentially result in a considerable demand for CO<sub>2</sub>.

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2. Use of carbon dioxide for hydrocarbon resource recovery presents the largest opportunity in terms of the amount that might be used annually but this sink has a finite lifetime. Estimates both the potential amount of carbon dioxide that could be utilized (then stored) and the economic value are considerable. Depending upon the scenario, the U.S. CO<sub>2</sub>-EOR potential demand could be 16 to 22.3 billion metric tonnes of carbon dioxide between now and 2050 with an average annual value in oil recovered of between \$4 and \$10 billion dollars. The global potential is larger, but was not quantified in this work.
3. The use of carbon dioxide to produce fuels is limited by the cost of hydrogen, or the relatively high cost of producing fuels from photosynthetic microorganisms. On the other hand, the production of chemicals is relatively more 'beneficial', although the amount of CO<sub>2</sub> used in these processes can be considerably lower than the CO<sub>2</sub>-to-fuels applications.
4. The use of CO<sub>2</sub> to produce chemicals, which have a slightly higher value compared to fuels is constrained by the difference in the cost of energy (hydrogen, electricity) required to produce the chemical and the price of the chemical. A DNV report notes that formic acid and carbon monoxide have a higher value from the energy required for their synthesis than conventional fuels such as methanol, ethylene and methane.
5. Other consumptive uses hold potential to provide a sustainable sink for carbon but the market size for these applications is far more limited, based on current markets, than resource recovery options and important aspects of the various relevant process chemistries need to be proven at scale. For instance, a series of carbonation processes claim benefits ranging between \$10 to \$300 per ton of carbon dioxide used, depending upon the products produced, but may consume as little as 20 million metric tonnes or up to 1.5 billion metric tonnes of carbon dioxide in a year if they saturate their target markets.
6. Carbonation approaches, which produce building materials or aggregates, still need to be demonstrated at a scale sufficient to prove their commercial viability. This sector of the economy consumes substantial quantities of these raw materials (concrete, aggregates, etc.) surpassing billion ton quantities globally. On the other hand, processes producing carbonates which cannot be used as building materials or aggregate (soda ash, baking soda) may mitigate CO<sub>2</sub> to a lesser extent. In the latter processes, the highest value, or quantity by-products, for instance hydrogen, present their own difficulties in developing the necessary infrastructure.
7. A number of other uses for carbon dioxide might offer indirect benefits through improved energy efficiency, through production of potable water from produced, saline waters, or simply by raising the efficiency of power cycles. These applications could improve overall efficiency from a system point of view.
8. In general, the resource recovery options are better understood, and closer to practical application. For many of the other opportunities, more work remains before they are technologically mature in applications that would use large amounts of carbon dioxide or yield substantial economic benefits.

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Novel approaches to reuse CO<sub>2</sub> continue to draw the attention of researchers. A recent publication<sup>119</sup> presents a summary of various efforts to use carbon dioxide in chemical synthesis, and notes that synthesis could account for up to 7% of global CO<sub>2</sub> emissions. Similarly, Rice University recently announced an initiative to explore uses of carbon dioxide<sup>120</sup>. Investors are also taking interest in CO<sub>2</sub> reuse. Biological, chemical and catalytic, and mineralization approaches to re-use CO<sub>2</sub> are described in a report by Prize Capital LLC<sup>121</sup>. One of the focus areas of the Joint Center for Artificial Photosynthesis (JCAP), a U.S. DOE Energy Innovation Hub, is the production of solar fuels from CO<sub>2</sub><sup>122</sup>. Therefore, this compendium of options is a snapshot in time which could be updated in the future as new advancements occur.

Finally, it is essential to apply sound analytic methodologies to assess the potential for use of any concept and to estimate the full range of benefits. Typical benefits include the amount of net-carbon dioxide removed from the atmosphere, the duration of such storage (if it is not consumed), the potential market value of a use, and the net-energetic impact. In the metrics tables, we refer to the need to apply sound life cycle assessment methodologies to appreciate the benefits (if any) of a candidate beneficial use. Some of the options discussed in this report involve incremental improvements to existing CO<sub>2</sub>-use processes, whereas others are ‘grey swans’, i.e. predictable high-risk, high-reward developments.

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<sup>119</sup> Aresta, M. ed., 2010. Carbon Dioxide as Chemical Feedstock, Wiley-VCH.

<sup>120</sup> Tour, J.M., Kittrell, C. & Colvin, V.L., 2010. Green carbon as a bridge to renewable energy. Nature Materials, 9(11), pp.871-874.

<sup>121</sup> Prize Capital LLC, 2011. Carbon capture and recycling industry overview.  
[http://www.prizecapital.net/Prize\\_Capital/CCR\\_Industry\\_Overview\\_Report.html](http://www.prizecapital.net/Prize_Capital/CCR_Industry_Overview_Report.html)

<sup>122</sup> <http://solarfuelshub.org/home>

## 8 Appendix

### Supporting documentation: Conversion of CO<sub>2</sub> to fuels and organic chemicals

#### CO<sub>2</sub> to Gasoline

44 T CO<sub>2</sub> = 14 T gasoline = 4939 gal gasoline. 138 billion gal/yr gasoline = 1229 million T CO<sub>2</sub>/yr. Synthetic hydrogen cost from Graves et al., 2010: 6 c/kWh, 53.5 kWh/kg H<sub>2</sub>. H<sub>2</sub> cost: 3.5 \$/kg H<sub>2</sub>. Gasoline cost: 2.4 \$/gal ([EIA](#), accessed 1/6/11). Gasoline demand: 138 billion gal/yr (<sup>378E6 gal/d</sup>, [EIA](#), accessed 1/6/11) = 391 million T/yr. 44 T CO<sub>2</sub> = 6 T H<sub>2</sub>. 1 T CO<sub>2</sub> = 6/44 T H<sub>2</sub> = 0.136 T H<sub>2</sub> = 0.136\*3500. Value of H<sub>2</sub> is 477.3 \$/T CO<sub>2</sub>. Sales value of gasoline is 378 million gal/d \* 2.4 \$/gal /3.233 million T CO<sub>2</sub>/d = 270 \$/T CO<sub>2</sub>. Net cost = -270 + 40 + 477.3 ≈ 247 \$/T CO<sub>2</sub>, or ca. 2200 \$/gal gasoline.

#### CO<sub>2</sub> to Diesel

44 T CO<sub>2</sub> = 14 T diesel = 4448 gal diesel. Diesel volume: 42x10<sup>9</sup> gal/yr = 416 million T CO<sub>2</sub>/yr. Diesel cost: 2.5 \$/gal ([EIA](#), accessed 1/6/11) = 105E9 \$/yr. This consumes 414E6 T CO<sub>2</sub>/yr. Gross benefits = -281 \$/T CO<sub>2</sub>. H<sub>2</sub> and CO<sub>2</sub> used in diesel cost the same as that used for gasoline. So net costs = -280 + 40 + 477 \$/T CO<sub>2</sub> = -237 \$/T CO<sub>2</sub>

#### CO<sub>2</sub> to Methanol

44 T CO<sub>2</sub> = 32 T methanol. Methanol market: 8 million T MeOH/yr ([Methanex](#), accessed 1/6/11). <sup>Metcalf Company</sup> = 11 million T CO<sub>2</sub>/yr. Methanol cost: 449 \$/T ([Methanex](#), accessed 1/6/11). Gross benefit: 449 \$/T MeOH\*8 million T MeOH/yr/11 million T CO<sub>2</sub>/yr = 327 \$/T CO<sub>2</sub>. H<sub>2</sub> and CO<sub>2</sub> costs the same as in diesel and gasoline production, 477 \$/T CO<sub>2</sub> and 40 \$/T CO<sub>2</sub>. Net cost = -327 \$/T CO<sub>2</sub> + 40 \$/T CO<sub>2</sub> cost + 477 \$/T CO<sub>2</sub> (hydrogen cost) = 190 \$/T CO<sub>2</sub>

#### CO<sub>2</sub> to Acrylic acid

U.S. acrylic acid capacity is ~1.2 million T/yr ([ICIS](#), accessed 1/6/11). 44 T CO<sub>2</sub> = 72 T acrylic acid (CH<sub>2</sub>=CH-COOH). Ethylene price from [ICIS](#) (accessed 1/6/11): 1135 to 1180 \$/T ethylene. 1 T CO<sub>2</sub> = 28/44 T ethylene = 28/44x1180 = 751 \$/T CO<sub>2</sub>. 44 T CO<sub>2</sub> = 72 T acrylic acid. Acrylic acid price from [PUDaily](#) (accessed 1/6/11): 1698 \$/T GAA. 1 T CO<sub>2</sub> = 72/44 T GAA = 72/44\*1698 = 2779 \$/T CO<sub>2</sub>. Net cost = -2779 (GAA cost)+ 40 (CO<sub>2</sub> cost)+ 751 (ethylene cost) = -1988 \$/T CO<sub>2</sub>. Net benefit = 1988 \$/T CO<sub>2</sub>

#### CO<sub>2</sub> to Polyethylene carbonate (PEC)

Polyethylene carbonate (PEC) market size in the U.S.: 5 million tonnes/year. CO<sub>2</sub> consumption: 5/2 = 2.5 million tonnes/year. Ethylene oxide (EtO) cost: 1200 \$/T, CO<sub>2</sub> cost: 40 \$/T, PEC cost: 1000 \$/T. Costs per ton of CO<sub>2</sub> are: 1200+40 = 1240 \$/T CO<sub>2</sub>. Value/T CO<sub>2</sub>: 1000x2 = 2000 \$/T CO<sub>2</sub>. Gross costs = -760 \$/T CO<sub>2</sub>. Gross benefits (negative costs): 2000 - 1240 = 760 \$/T CO<sub>2</sub>.

## Algae Fuels

Table A-1: Summary of various algae technologies producing value-added fuels, chemicals and raw materials from photosynthetic microorganisms

	Biofuel Production from Algae		Multiple-purpose Algae Technologies
	Raceway Systems/ Hybrid Systems	Closed Systems/Photobioreactors (PBR)	
<b>Yield, gallons of 'oil'/acre/year</b>	Hybrid systems may achieve 10,000 gal/acre/yr <sup>123</sup> , raceway ponds ~3,000-5,000	Up to 15,000	NA
<b>Yields, g dry, ash-free biomass/m<sup>2</sup>/d</b>	10 to 50	Higher than 10 to 50	NA
<b>CO<sub>2</sub> Re-used, T/acre/year (2 g CO<sub>2</sub>/g biomass)</b>	30 to 150	Higher than 30 to 150	NA
<b>Type of algae/microorganisms</b>	Cultured strains, genetically engineered microalgae, cyanobacteria and other microbes		Wild/cultured strains of microalgae and other photosynthetic microorganisms
<b>Current State of Development</b>	Four companies received U.S. DOE funding for pilot-scale biorefineries processing algae in 2010.		
<b>Inputs</b>	Salt/brackish water, nutrients, CO <sub>2</sub> , algal cultures, biomass/sunlight		Municipal wastewater, marine/brackish water (little additional nutrients)
<b>Cell Harvesting and Dewatering</b>	Processes include centrifugation, vacuum filtration	Some may not require separation, others may use mechanical/chemical processes	Fish feeding on microalgae, wild algae harvesting/processing/refining
<b>Product Recovery &amp; Refining</b>	Solvent extraction, in vivo/ex vivo fermentation, transesterification, biocrude processing at refineries (hydrogenation, cracking/thermal pyrolysis, decarboxylation), gasification and anaerobic digestion of spent biomass		Fish processing, biocrude processing/refining operations similar to the open/closed systems
<b>Products</b>	Ethanol, liquid hydrocarbons, biodiesel, petroleum		Omega-3 fatty acids, fish feed, fish protein, algal protein, biopolymer

<sup>123</sup> See Huntley and Redalje, 2006 for an estimate of the potential performance of a coupled system of photobioreactors and open-pond batch cultures.

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	diesel, methane, dry process fuels, and electricity	precursors, treated waste water, petroleum fractions, specialty solvents, surfactants	
<b>Representative Examples</b>	PetroAlgae, Sapphire Energy, HR BioPetroleum	Solix, Joule Unlimited, Algenol, Solazyme	Aurora Algae, Aquaflow/UOP, Live Fuels

In a recent conceptual study of biofuel-focused algae production using wastewater, Lundquist et al. estimated production costs of 240 to 330 \$/bbl (of biodiesel) for a site located in California. In comparison, cases where algae production was considered as a part of wastewater treatment, the production costs were considerably lower, at 28 \$/bbl of biodiesel. The use of spent algal biomass as animal feed, or for the production of high-value products such as carotenoids and pigments could improve the economics of algal biofuel production.

However, Lundquist et al. (2010) note that the market demand for high-value products such as pigments, is somewhat limited (order of tons) and would be easily overcome by large-scale algal biofuel production. The use of algal biomass to produce animal feed would require additional processing steps, including the removal of heavy metals, which would increase capital and operating costs. Reducing the costs of algae cultivation, harvesting, oil extraction and further processing are required to commercialize large-scale algal biofuel production and the beneficial use of CO<sub>2</sub>. In Table A-1, the technologies are arbitrarily classified based on algae productivity, as: (1) raceway systems/hybrid systems, (2) closed systems/photobioreactors for producing algal biofuels and, (3) multi-purpose algae technologies whose end products include biofuels, fine chemicals, protein, wastewater treatment and other uses.

## 9 Bibliography

Algal Biomass Organization, 2011. Algae biofuels edge closer to commercialization. Available at: <http://www.algalbiomass.org/news/2064/algae-biofuels-edge-closer-to-commercialisation/> [Accessed February 2, 2011].

Allen, S. et al., 2010. Polycarbonate block copolymers. U.S. Patent 2009/062703.

Aresta, M. 2010, Carbon Dioxide as Chemical Feedstock, pp. 1-13, Wiley-VCH

Balaraman, E. et al., 2011. Efficient hydrogenation of organic carbonates, carbamates and formates indicates alternative routes to methanol based on CO<sub>2</sub> and CO. Nature Chemistry, 3(8), pp.609-614.

Baldwin, B.A. et al., 2009. Using magnetic resonance imaging to monitor CH<sub>4</sub> hydrate formation and spontaneous conversion of CH<sub>4</sub> hydrate to CO<sub>2</sub> hydrate in porous media. Magnetic Resonance Imaging, 27(5), pp.720-726.

Bartels, Jeffrey R., Michael B. Pate, and Norman K. Olson. 2010, An economic survey of hydrogen production from conventional and alternative energy sources. International Journal of Hydrogen Energy, v.35 (16) (August): 8371-8384, Available at: doi:10.1016/j.ijhydene.2010.04.035 [ Accessed 10/24/2011].

Bartis, J.T. & Van Bibber, L., 2011. Alternative fuels for military applications, Monograph MG-969-OSD, RAND Corporation. Available at: <http://www.rc.rand.org/pubs/monographs/MG969.html> [Accessed January 28, 2011].

Beckman, E.J., Supercritical and near-critical CO<sub>2</sub> in green chemical synthesis and processing, J. of Supercritical Fluids 28 (2004) 121–191

Beer, L.L. et al., 2009. Engineering algae for biohydrogen and biofuel production. Current Opinion in Biotechnology, 20(3), pp.264-271.

Benson, S. et al., 2004. GEO-SEQ Best practices manual: geologic carbon dioxide sequestration: from site selection to implementation, 9/30/2004: Lawrence Berkeley National Laboratory, Available at: <http://escholarship.org/uc/item/27k6d70j>

Birkedal, K.A., 2009. Hydrate Formation and CH<sub>4</sub> production from natural gas hydrates - Emphasis on boundary conditions and production methods. Master's Thesis. Norway: University of Bergen. Available at: <https://bora.uib.no/bitstream/1956/3425/1/56365022.pdf> [Accessed December 3, 2010].

Calera Corporation, 2009. Sequestering CO<sub>2</sub> in the built environment, May 14<sup>th</sup>, 2009, [www.usea.org/Publications/Documents/Sequestering\\_CO2.pdf](http://www.usea.org/Publications/Documents/Sequestering_CO2.pdf)

Carbon Capture Journal, 2010. Skyonic awarded DOE grant for CO<sub>2</sub> reuse project. Carbon Capture Journal. Available at: <http://www.carboncapturejournal.com/displaynews.php?NewsID=511> [Accessed September 30, 2010].

Carbon Capture Journal, 2011. Maersk Oil – plan to make CCS pay for itself. Issue 19. Available at: <http://www.carboncapturejournal.com/displaynews.php?NewsID=732> [Accessed March 31, 2011].

Carbon Dioxide Transportation and Sequestration Act, 2011, Available at: <http://www.ilga.gov/legislation/fulltext.asp?DocName=&SessionId=84&GA=97&DocTypeId=SB&DocNum=1821&GAID=11&LegID=57876&SpecSess=&Session>, [Accessed: 9/28/2011].

*Draft*

Carbon Sense Solutions, Technology Update - Summer 2010. Available at: <http://carbonsensesolutions.com/wp-content/uploads/2010/01/CSS-Technology-Update-July10.pdf> [Accessed September 2, 2010].

Chiang, S.-H., Klinzing, G.E., He, D.-X., Feng, Y.-R., Yu, S.-N., Jenkins, K., Diffendal, G., 1994. Update of the LICADO Coal Cleaning Process, Advanced physical coal cleaning session, Proceedings of the Tenth Annual Coal Preparation, Utilization, and Environmental Control Contractors Conference, CONF-940780, Volume 1, part 2, p.67-74, July 18-21, 1994, Pittsburgh, PA. Available at:

[http://www.fischer-tropsch.org/DOE/conf\\_proc/Coal%20Conferences/940780-Vol-1%20%2008-01-94/CONF-940780-Vol-1,%20Part%202,%20Pages%2055%20-%20116.pdf](http://www.fischer-tropsch.org/DOE/conf_proc/Coal%20Conferences/940780-Vol-1%20%2008-01-94/CONF-940780-Vol-1,%20Part%202,%20Pages%2055%20-%20116.pdf) [Accessed December 6, 2010].

Chisti, Y., 2007. Biodiesel from microalgae. *Biotechnology Advances*, 25(3), pp.294-306.

Chisti, Y., 2008. Response to Reijnders: Do biofuels from microalgae beat biofuels from terrestrial plants? *Trends in Biotechnology*, 26(7), pp.351-352.

Concrete Products, 2010. Canadians test CO<sub>2</sub> capture via concrete block curing. Available at: <http://concreteproducts.com/concretecurrents/Canadians-test-CO2-capture-via-block-curing-0726/> [Accessed September 1, 2010].

Constantz, B., Monteiro, P.J.M. et al., 2010a. United States Patent: 7754169 - Methods and systems for utilizing waste sources of metal oxides. [Accessed October 6, 2010].

Constantz, B., Youngs, A., O'Neil, J., Farsad, K., Patterson, J., Stagnaro, J., Thatcher, R. & Camire, C., 2010b. United States Patent: 7753618 - Rocks and aggregate, and methods of making and using the same. [Accessed October 6, 2010].

Constantz, B.R., Clodic, L., Ryan, C., Fernandez, M. et al., 2010c. United States Patent: 7749476 - Production of carbonate-containing compositions from material comprising metal silicates. [Accessed October 6, 2010].

Constantz, B.R., Farsad, K. & Fernandez, M., 2010d. United States Patent: 7744761 - Desalination methods and systems that include carbonate compound precipitation. [Accessed October 6, 2010].

Constantz, B.R., Youngs, A. & Holland, T.C., 2010e. United States Patent: 7771684 - CO<sub>2</sub>-sequestering formed building materials. [Accessed October 6, 2010].

CSLF, 2010. 2010 Carbon sequestration leadership forum technology roadmap, Available at: [http://www.cslforum.org/publications/documents/CSLF\\_Technology\\_Roadmap.pdf](http://www.cslforum.org/publications/documents/CSLF_Technology_Roadmap.pdf) [Accessed November 10, 2010].

Davidson, S., 2005. A red mud remedy. *ECOS*, 35(127). Available at: [http://www.ecomagazine.com/?act=view\\_file&file\\_id=EC127p35.pdf](http://www.ecomagazine.com/?act=view_file&file_id=EC127p35.pdf) [Accessed July 22, 2010].

Dilmore, R.M., 2010, An assessment of gate-to-gate environmental life cycle performance of water-alternating-gas CO<sub>2</sub>-enhanced oil recovery in the Permian Basin: DOE/NETL-2010/1433. Available at: <http://www.netl.doe.gov/energy-analyses/refshelf/PubDetails.aspx?Action=View&PubId=333>

EERE, 2011, Department of Energy announces \$20 Million to boost development of innovative geothermal technologies, Available at: [http://apps1.eere.energy.gov/news/progress\\_alerts.cfm/pa\\_id=401](http://apps1.eere.energy.gov/news/progress_alerts.cfm/pa_id=401), [Accessed 9/28/2011].

*Draft*

- Fernando, Q., et al., 1991. Formation of rare earth carbonates using supercritical carbon dioxide, US Patent 5,045,289.
- Gilliam, R.J. et al., 2010. Electrochemical production of an alkaline solution using CO<sub>2</sub>. U.S. Patent 2010/0084280. Available at: [Accessed January 14, 2011].
- Goel, N., 2006. In situ methane hydrate dissociation with carbon dioxide sequestration: Current knowledge and issues. *Journal of Petroleum Science and Engineering*, 51(3-4), pp.169-184.
- Graves, C. et al., 2011, Sustainable hydrocarbon fuels by recycling CO<sub>2</sub> and H<sub>2</sub>O with renewable or nuclear energy. *Renewable and Sustainable Energy Reviews*, v.15(1), pp.1-23.
- Greenwell, H.C. et al., 2010. Placing microalgae on the biofuels priority list: a review of the technological challenges. *Journal of The Royal Society Interface*, 7(46), pp.703 -726.
- Freihauf, K.E., 2009. Simulation and design of energized hydraulic fractures. Ph.D. Thesis. Austin, TX: The University of Texas at Austin. Available at: <http://www.pge.utexas.edu/theses09/friehauf.pdf>.
- Hamilton, T., 2008. Technology Review: A concrete fix to global warming. *Technology Review*. Available at: <http://www.technologyreview.com/Energy/21117/> [Accessed September 1, 2010].
- Hargrove, B., Melzer, L.S., Whitman, L., 2010, A status report on North American CO<sub>2</sub> EOR production and CO<sub>2</sub> supply: Presented at the 16<sup>th</sup> Annual CO<sub>2</sub> Flooding Conference, December 9-10, 2010, Midland, TX.
- Heffer, P., Prud'homme, M., Short-Term Fertilizer Outlook 2010-2011, 36th IFA Enlarged Council Meeting, New Delhi, December 2010. Available at: [http://www.fertilizer.org/ifacontent/download/48774/709486/version/1/file/2010\\_council\\_newdelhi\\_ifa\\_outlook.pdf](http://www.fertilizer.org/ifacontent/download/48774/709486/version/1/file/2010_council_newdelhi_ifa_outlook.pdf), [Accessed February 1, 2011].
- Hejzlar et al., Assessment of gas cooled fast reactor with indirect supercritical CO<sub>2</sub> cycle, *Nuclear Engineering and Technology*, v.38(2), Special Issue on ICAP'05
- Hunter R., Lewis, S., Resource characterization and quantification of natural gas hydrate and associated free-gas accumulations in the Prudhoe Bay – Kuparuk River area on the North Slope of Alaska, 2Q2010-3Q2010 Semi-Annual Progress Report, Available at: [http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/2010Reports/NT41332\\_SemiAnnApr-Sep2010.pdf](http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/2010Reports/NT41332_SemiAnnApr-Sep2010.pdf), [Accessed December 2, 2010].
- Huntley, M.E. & Redalje, D.G., 2006. CO<sub>2</sub> Mitigation and Renewable Oil from Photosynthetic Microbes: A New Appraisal. *Mitigation and Adaptation Strategies for Global Change*, 12(4), pp.573-608.
- IEA GHG, 2009. Storage in depleted gas fields, IEA GHG Technical Report, 2009/1, Available at: <http://www.ieaghg.org/index.php?technical-reports-2009.html>
- Ikegawa, Y. et al., 2010. SS: Hydrates: Experimental results for long term CO<sub>2</sub> injection near methane hydrate formations. In *Proceedings of Offshore Technology Conference*. Available at: <http://www.onepetro.org/mslib/servlet/onepetropreview?id=OTC-20575-MS&soc=OTC> [Accessed December 2, 2010].
- James, R.E. & McGurl, G.V., 2004. IGCC system analysis utilizing various condenser cooling platforms, including CO<sub>2</sub> sequestration and water desalination. *Proceedings of the Water Environment Federation*, 2004, pp.720-737(18).
- Jones, J.D., 2010. United States Patent: 7727374 - Removing carbon dioxide from waste streams through co-generation of carbonate and/or bicarbonate minerals.

*Draft*

Kirk, D.W. et al., 2010. United States Patent: 7790012 - Low energy electrochemical hydroxide system and method. [Accessed October 6, 2010]

Klauber, C., Grafe, M. & Power, G., 2009. Review of Bauxite Residue "Re-use" Options, CSIRO Document, DMR-3609, Available at: [http://asiapacificpartnership.org/pdf/Aluminium/6th\\_aluminium\\_tf\\_meeting/Review\\_of\\_Bauxite\\_Residue\\_Re-use\\_Options\\_Aug09\\_sec.pdf](http://asiapacificpartnership.org/pdf/Aluminium/6th_aluminium_tf_meeting/Review_of_Bauxite_Residue_Re-use_Options_Aug09_sec.pdf) [Accessed July 22, 2010].

Kreutz, T., 2011. Prospects for producing low carbon transportation fuels from captured CO<sub>2</sub> in a climate constrained world. Energy Procedia, 4(0), pp.2121-2128.

Krotz, D., 2011, Store CO<sub>2</sub> underground and extract electricity? A Berkeley Lab-led team is working on it, Available at: <http://newscenter.lbl.gov/feature-stories/2011/08/08/geothermal-co2/>, [Accessed 9/28/2011].

Koottungal, L., 2010. Special report: EOR/heavy oil survey: 2010 worldwide EOR survey. Oil & Gas Journal. Available at: [http://www.ogj.com/index/article-display.articles.oil-gas-journal.volume-108.issue-14.technology.special-report\\_eor0.html](http://www.ogj.com/index/article-display.articles.oil-gas-journal.volume-108.issue-14.technology.special-report_eor0.html) [Accessed October 21, 2010].

Kuuskraa, V., Ferguson, R. & Van Leewen, T., 2010. Storing CO<sub>2</sub> and producing domestic crude oil with next generation CO<sub>2</sub>-EOR technology: An update, Report prepared for U.S. DOE/NETL, Office of Systems, Analyses and Planning, DOE/NETL-2010/1417/04-30-10, April 30, 2010. [http://www.netl.doe.gov/energy-analyses/pubs/Storing%20CO2%20w%20EOR\\_FINAL.pdf](http://www.netl.doe.gov/energy-analyses/pubs/Storing%20CO2%20w%20EOR_FINAL.pdf)

Lawrence, M. & Wheelock, C., 2010. Algae-Based Biofuels - Demand Drivers, Policy Issues, Emerging Technologies, Key Industry Players, and Global Market Forecasts. Executive summary available at: <http://www.pikeresearch.com/research/algae-based-biofuels> [Accessed February 2, 2011].

Lee, J., 2009. China's Ring of Power. Foreign Policy. Available at: [http://www.foreignpolicy.com/articles/2009/09/09/going\\_green](http://www.foreignpolicy.com/articles/2009/09/09/going_green) [Accessed September 29, 2011].

Lyon, R.K., 2004, United States Patent: 6733573 - Catalyst allowing conversion of natural gas hydrate and liquid CO<sub>2</sub> to CO<sub>2</sub> hydrate and natural gas. Available at: <http://uspto.gov> [Accessed December 3, 2010].

Lundquist, T.J. et al., 2010. A realistic technology and engineering assessment of algae biofuel production, Energy Biosciences Institute. Available at: [http://digitalcommons.calpoly.edu/cenv\\_fac/188](http://digitalcommons.calpoly.edu/cenv_fac/188) [Accessed February 2, 2011].

Liao, S., Brunner, F. & Mattar, L., 2009. Impact of ignoring CO<sub>2</sub> injection volumes on post-frac PTA. In Proceedings of Canadian International Petroleum Conference. Available at: <http://www.onepetro.org/mslib/servlet/onepetroreview?id=PETSOC-2009-124&soc=PETSOC> [Accessed November 22, 2010].

Linde, [http://www.lindegasbenelux.com/international/web/lg/us/likelgus30.nsf/docbyalias/nav\\_frac\\_co2#1](http://www.lindegasbenelux.com/international/web/lg/us/likelgus30.nsf/docbyalias/nav_frac_co2#1)

Lyon, R.K., 2004, United States Patent: 6733573 - Catalyst allowing conversion of natural gas hydrate and liquid CO<sub>2</sub> to CO<sub>2</sub> hydrate and natural gas. Available at: <http://uspto.gov> [Accessed December 3, 2010].

Max, M.D., 2006. Hydrate desalination for water purification. US 6,991,722 B2

Mazza, R.L., 2001. Liquid-Free CO<sub>2</sub>/Sand Stimulations: An Overlooked Technology - Production Update. In Proceedings of SPE Eastern Regional Meeting. SPE Eastern Regional Meeting. Available at:

<http://www.onepetro.org/mslib/servlet/onepetroreview?id=00072383&soc=SPE>

[Accessed November 9, 2010].

McCormack, R. A. and Andersen, R. K. 1995. Clathrate desalination plant preliminary research study. Water Treatment Technology Program Rept. No. 5. Thermal Energy Storage, Inc. San Diego, CA. United States Department of Interior, Bureau of Reclamation.

McGrail, B.P. et al., 2007. Using carbon dioxide to enhance recovery of methane from gas hydrate reservoirs: Final Summary Report, PNNL-17035, Available at: <http://www.osti.gov/bridge/servlets/purl/929209-jP39G7/> [Accessed December 2, 2010].

Mehta, R., 2008. Concrete carbonation. Materials World Magazine, (October 2008). Available at: <http://www.iom3.org/news/concrete-carbonation> [Accessed September 1, 2010].

Melzer, L.S., 2011, Testimony before the United States Senate Committee on Energy and Natural Resources hearing on oil and gas technologies, May 10, 2011. Available at: <http://energy.senate.gov/public/files/MelzerTestimony05102011.pdf>.

Metz, B. et al. eds., 2005. IPCC, 2005: IPCC special report on carbon dioxide capture and storage, Chapter 7. Prepared by Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, 442pp and references therein.

Minutillo, M. & Perna, A., 2009. A novel approach for treatment of CO<sub>2</sub> from fossil fired power plants, Part A: The integrated systems ITRPP. International Journal of Hydrogen Energy, 34(9), pp.4014-4020.

Minutillo, M. & Perna, A., 2010. A novel approach for treatment of CO<sub>2</sub> from fossil fired power plants. Part B: The energy suitability of integrated tri-reforming power plants (ITRPPs) for methanol production. International Journal of Hydrogen Energy, 35(13), pp.7012-7020.

Moisseytsev, A. and Sienicki, J.J., Supercritical CO<sub>2</sub>-Brayton cycle control strategy for autonomous liquid metal-cooled reactors, presented at Americas Nuclear Energy Symposium, 2004, Miami Beach, Florida, October 3-6, 2004

Monkman, S. & Shao, Y., 2010. Integration of carbon sequestration into curing process of precast concrete. Canadian Journal of Civil Engineering, 37(2), 302-310.

Morello, J. & Pate, R., 2010. DOE-EERE-Office of Biomass Program Webinar. The promise and challenge of algae as renewable source of biofuels. Available at: [www1.eere.energy.gov/biomass/pdfs/algae\\_webinar.pdf](http://www1.eere.energy.gov/biomass/pdfs/algae_webinar.pdf) [Accessed February 3, 2011].

NEA Nuclear Science Committee, 1997. Actinide separation chemistry in nuclear waste streams and materials, NEA/NSC/DOC(1997)19, Nuclear Energy Agency, Organisation for Economic Co-operation and Development. Available at: <http://www.oecd-nea.org/science/docs/1997/index.html> [Accessed December 3, 2010].

NETL, 2004, Combining power generation and carbon sequestration using a Direct FuelCell®, Available at: [www.netl.doe.gov/publications/factsheets/project/Proj319.pdf](http://www.netl.doe.gov/publications/factsheets/project/Proj319.pdf), [Accessed 10/31/2011].

NETL, 2010. Impact of the Marcellus Shale gas play on current and future CCS activities, Available at: [http://www.netl.doe.gov/technologies/carbon\\_seq/refshelf/Marcellus\\_CCS.pdf](http://www.netl.doe.gov/technologies/carbon_seq/refshelf/Marcellus_CCS.pdf).

*Draft*

NETL/ESPA, Kuuskraa V., Van Leeuwen, T., Wallace, M., 2011. Improving Domestic Energy Security and Lowering CO<sub>2</sub> Emissions with "Next-Generation" CO<sub>2</sub>-Enhanced Oil Recovery (CO<sub>2</sub>-EOR), DOE/NETL-2011/1504, Available at: [http://www.netl.doe.gov/energy-analyses/pubs/NextGen\\_CO2\\_EOR\\_06142011.pdf](http://www.netl.doe.gov/energy-analyses/pubs/NextGen_CO2_EOR_06142011.pdf) [Accessed August 15, 2011]

Niven, R. & Ghoshal, S., 2006. Sequestering carbon dioxide by accelerated concrete curing. Available at: <http://www.netl.doe.gov/publications/proceedings/06/carbon-seq/Tech%20Session%20054.pdf>.

Nutall, B. C., J. A. Drahoval, C. Eble and R. M. Bustin, 2005, CO<sub>2</sub> Sequestration in gas shales of Kentucky, Search and Discovery Article #40171, Available at: [www.searchanddiscovery.net/documents/2005/nutall/index.htm](http://www.searchanddiscovery.net/documents/2005/nutall/index.htm), Accessed November 10, 2010.

O'Connor, W.K., D.C. Dahlin, G.E. Rush, S.J. Gedermann, L.R. Penner, D.N. Nilsen, 2005. Aqueous mineral carbonation, Final Report, DOE/ARC-TR-04-002.

Oh, C.H., et al., 2006. Development of a supercritical carbon dioxide Brayton Cycle: Improving VHTR efficiency and testing material compatibility - Final Report, INL/EXT-06-01271, Idaho National Laboratory

Oloman, C. & Li, H., 2007. Continuous Co-current Electrochemical Reduction of Carbon Dioxide. WO 2007/041872 A1. Available at: <http://www.wipo.int/patentscope/search/en/WO2007041872> [Accessed July 27, 2011].

Pebdani, F. & Shu W., 1986, US Patent 4565249, Heavy oil recovery process using cyclic carbon dioxide steam stimulation,

Petrusak, R., 2011, Assessing factors influencing CO<sub>2</sub> storage capacity and injectivity in gas shales – Review of current activities, Presented at the 7<sup>th</sup> International Forum on Geological Sequestration of CO<sub>2</sub> in Coal Seams and Gas Shale Reservoirs, March 7-8, 2011, Houston, TX, Available at: [http://coal-seq.com/proceedings2011/presentations/8\\_Robin%20Petrusak\\_ARI.pdf](http://coal-seq.com/proceedings2011/presentations/8_Robin%20Petrusak_ARI.pdf) [Accessed: 10/19/2011].

Pienkos, P.T.; Darzins, A., 2009. The promise and challenges of microalgal-derived biofuels. BioFPR (3); 431–440.

Phelps, T.J. et al., 2005. Method for excluding salt and other soluble materials from produced water. US 2007/004945 A1, [Accessed October 26, 2010].

Phillips, J., Program on technology innovation: Advanced concepts in slurry-fed low-rank coal gasification – Liquid CO<sub>2</sub>/coal slurries and hot water drying, Report #1014432, Technical Update, December 2006

Platts, 2011, Illinois governor signs CO<sub>2</sub> legislation to aid pipeline projects, Available at: <http://www.platts.com/RSSFeedDetailedNews/RSSFeed/Coal/6408491>, [Accessed: 9/28/2011].

Priestnall, M., 2010. CO<sub>2</sub> mineralisation via fuel cells. How to make CCS profitable, Finding Petroleum CCS Forum, Geological Society, London. Available at: <http://www.findingpetroleum.com/files/event15/ccs.pdf>. [Accessed 4 February, 2011].

Prize Capital LLC, 2011. Carbon capture and recycling industry overview. Available at: [http://www.prizecapital.net/Prize\\_Capital/CCR\\_Industry\\_Overview\\_Report.html](http://www.prizecapital.net/Prize_Capital/CCR_Industry_Overview_Report.html).

Rawlins, C.H., 2008. Geological sequestration of carbon dioxide by hydrous carbonate formation in steelmaking slag. Ph.D. Dissertation, Metallurgical Engineering, Missouri University of Science and Technology. Available at: [http://scholarsmine.mst.edu/thesis/Geological\\_sequestra\\_09007dcc804e3ed5.html](http://scholarsmine.mst.edu/thesis/Geological_sequestra_09007dcc804e3ed5.html) [Accessed October 8, 2010].

*Draft*

Reeves, S.R., Assessment of CO<sub>2</sub> sequestration and ECBM potential of US coalbeds, Topical Report, DOE Contract No. DE-FC26-00NT40924, February 2003.

Reppas, N.B. & Ridley, C.P., 2010. Methods and compositions for the recombinant biosynthesis of n-alkanes. U.S. patent 7794969. Available at: [http://www.patentlens.net/patentlens/patent/US\\_7794969/en/](http://www.patentlens.net/patentlens/patent/US_7794969/en/) [Accessed January 28, 2011].

Roop, S.R., et al., 2003. Year 4 report on the technical and economic feasibility of a freight pipeline in Texas, Report 9-1519-4, Texas Transportation Institute, Sponsored by the Texas Department of Transportation In Cooperation with the U.S. Department of Transportation Federal Highway Administration.

Saar, M.O., Randolph, J.B. & Kuehn, T.H., 2010. Carbon dioxide-based geothermal energy generation systems and methods related thereto, WO 2010/104599 A2, [Accessed December 3, 2010].

Santhanam, C.J., Hanks, R.W. & Stickles, R.P., 1988. United States Patent: 4721420 - Pipeline transportation of coarse coal-liquid carbon dioxide slurry. Available at: <http://uspto.gov>. [Accessed December 3, 2010].

Schlumberger, [http://www.slb.com/services/stimulation/tight\\_gas\\_stimulation/thermafoam.aspx](http://www.slb.com/services/stimulation/tight_gas_stimulation/thermafoam.aspx)

Schlumberger, [http://www.slb.com/resources/other\\_resources/product\\_sheets/stimulation/clearfrac\\_co2.aspx](http://www.slb.com/resources/other_resources/product_sheets/stimulation/clearfrac_co2.aspx)

Sheehan, J., Dunahay, T., Benemann, J. and Roessler, P.: 1998. A Look Back at the U.S. Department of Energy's Aquatic Species Program – Biodiesel From Algae, Golden, CO, National Renewable Energy Institute, NREL/TP-580-24190, 328 pp.

Sheps, K., 2007. Seawater desalination as a factor of oceanic CO<sub>2</sub> disposal. Presented at CHEMRAWN XVII and ICCDU-IX Conference on Greenhouse Gases - Mitigation and Utilization, Kingston, Ontario, 8 – 12 July 2007. Available at: <http://www.chem.queensu.ca/Conferences/CHEMRAWN/Sheps.pdf> [Accessed October 26, 2010].

Sheps, K. et al., 2009. A case for deep-ocean CO<sub>2</sub> sequestration. Energy Procedia, 1(1), pp.4961-4968.

Sceats, M.G. & Horley, C.J., 2011., Material compound and a method of fabricating the same, United States Patent Application: 2011/0011142.

Simmons, B.A. et al., 2008. Desalination utilizing clathrate hydrates (LDRD final report, SAND2007-6565, Sandia National Laboratories)., Available at: <http://www.osti.gov/bridge/servlets/purl/934586-mQC25H/> [Accessed October 26, 2010].

Sivaraman, A., 2005. United States Patent Application 2005/0121200 A1. Process to sequester CO<sub>2</sub> in natural gas hydrate fields and simultaneously recover methane. Available at: <http://uspto.gov> [Accessed December 3, 2010].

Sridhar, N. & Hill, D., 2011. Carbon Dioxide Utilization, Electrochemical Conversion of CO<sub>2</sub> – Opportunities and Challenges, Research and Innovation position paper, 07-2011, Available at: [http://www.dnv.com/binaries/DNV-position\\_paper\\_CO2\\_Utilization\\_tcm4-445820.pdf](http://www.dnv.com/binaries/DNV-position_paper_CO2_Utilization_tcm4-445820.pdf). [Accessed March 31, 2011].

Skyonic, 2010. DE-FOA-0000015 Skyonic Phase II Application.

Styring et al., 2011, Carbon Capture and Utilisation in the Green Economy, Centre for Low Carbon Futures, Report 501, Available at:

[http://www.lowcarbonfutures.org/assets/media/clcf\\_ccu\\_report\\_21\\_july\\_final\\_sm.pdf.pdf](http://www.lowcarbonfutures.org/assets/media/clcf_ccu_report_21_july_final_sm.pdf.pdf). [Accessed 27 July, 2011].

Tanninen, J. & Nyström, M., 2002. Separation of ions in acidic conditions using NF. *Desalination*, 147(1-3), pp.295-299.

Tour, J.M., Kittrell, C. & Colvin, V.L., 2010. Green carbon as a bridge to renewable energy. *Nature Materials*, 9(11), pp.871-874.

Trican, <http://www.trican.ca/Services/technologyfracturingliquidco2.aspx>

U.S. DOE, [http://www.netl.doe.gov/technologies/carbon\\_seq/core\\_rd/storage.html](http://www.netl.doe.gov/technologies/carbon_seq/core_rd/storage.html)

U.S. DOE, [http://www.fe.doe.gov/programs/oilgas/eor/Ten\\_Basin-Oriented\\_CO2-EOR\\_Assessments.html](http://www.fe.doe.gov/programs/oilgas/eor/Ten_Basin-Oriented_CO2-EOR_Assessments.html)

U.S. Geological Survey, 2010. Soda ash 2010 mineral commodity summary, [http://minerals.usgs.gov/minerals/pubs/commodity/soda\\_ash/mcs-2010-sodaa.pdf](http://minerals.usgs.gov/minerals/pubs/commodity/soda_ash/mcs-2010-sodaa.pdf)

U.S. Geological Survey, 2009a, Construction sand and gravel statistics, in Kelly, T.D., and Matos, G.R., comps., *Historical statistics for mineral and material commodities in the United States: U.S. Geological Survey Data Series 140*, available online at <http://pubs.usgs.gov/ds/2005/140/>. [Accessed 10/6/2010].

U.S. Geological Survey, 2009b, Cement statistics, in Kelly, T.D., and Matos, G.R., comps., *Historical statistics for mineral and material commodities in the United States: U.S. Geological Survey Data Series 140*, available online at <http://pubs.usgs.gov/ds/2005/140/>. [Accessed 10/6/2010].

U.S. Geological Survey, 2009c, Soda ash statistics, in Kelly, T.D., and Matos, G.R., comps., *Historical statistics for mineral and material commodities in the United States: U.S. Geological Survey Data Series 140*, available online at <http://pubs.usgs.gov/ds/2005/140/>. [Accessed 10/6/2010].

U.S. Geological Survey, 2009d, Aluminum statistics, in Kelly, T.D., and Matos, G.R., comps., *Historical statistics for mineral and material commodities in the United States: U.S. Geological Survey Data Series 140*, available online at <http://pubs.usgs.gov/ds/2005/140/>. [Accessed 10/6/2010].

U.S. Geological Survey, 2009e, Iron and steel statistics, in Kelly, T.D., and Matos, G.R., comps., *Historical statistics for mineral and material commodities in the United States: U.S. Geological Survey Data Series 140*, available online at <http://pubs.usgs.gov/ds/2005/140/>. [Accessed October 8, 2010].

U.S. Geological Survey, 2009f, Iron and steel slag statistics, in Kelly, T.D., and Matos, G.R., comps., *Historical statistics for mineral and material commodities in the United States: U.S. Geological Survey Data Series 140*, available online at <http://pubs.usgs.gov/ds/2005/140/>. [Accessed October 8, 2010].

Van Leewen, T., Ferguson, R., & Kuuskraa, V., 2009. Electricity use of enhanced oil recovery with carbon dioxide (CO<sub>2</sub>-EOR), report prepared for U.S. DOE/NETL, Office of Systems, Analyses and Planning, DOE/NETL-2009/1354/01-26-09, Jan 26, 2009. <http://www.netl.doe.gov/energy-analyses/pubs/Electricity%20Use%20of%20CO2-EOR.pdf>

Vlasopoulos, N., 2010. Novacem carbon-negative cement, presentation for the Society of Chemical Industry, London. Available at: <http://novacem.com/wp-content/uploads/2010/12/20101125-Technical-update.pdf> [Accessed January 11, 2010].

Vlasopoulos, N. & Cheeseman, C., 2009. Binder composition. WO/2009 156740. Available at: <http://www.wipo.int/pctdb/en/ia.jsp?ia=GB2009/001610> [Accessed January 11, 2011].

Wender, I., 1996. Reactions of synthesis gas. *Fuel Processing Technology*, 48(3), pp.189-297.

*Draft*

Wethe, J.D. & Waters, W.M., 1976. United States Patent: 3971211 - Thermodynamic cycles with supercritical CO<sub>2</sub> cycle topping. Available at: <http://uspto.gov>, [Accessed December 3, 2010] and <http://www.echogen.com/products>

Wijffels, R.H. & Barbosa, M.J., 2010. An Outlook on Microalgal Biofuels. *Science*, 329(5993), pp.796 -799.

Wikipedia, [http://en.wikipedia.org/wiki/List\\_of\\_alumina\\_refineries#Smelter-grade\\_alumina\\_refineries](http://en.wikipedia.org/wiki/List_of_alumina_refineries#Smelter-grade_alumina_refineries)

Wildgust, N., 2009, Global CO<sub>2</sub> geological storage capacity in hydrocarbon fields, presented at IEA GHG Weyburn-Midale Monitoring Project PRISM meeting, June 2009, Regina, Canada

Wildgust, N., 2009, Global mapping of CO<sub>2</sub> sources and sinks, presented at NACAP Workshop, 22-23 June 2009, Pittsburgh, USA

Wilson, S.J. et al., Alaska North Slope regional gas hydrate production modeling forecasts. *Marine and Petroleum Geology*, In Press, Corrected Proof. Available at: <http://www.sciencedirect.com/science/article/B6V9Y-4YMPXBH-1/2/6a47c6322e7c6c18fab05573d2c1e270> [Accessed December 3, 2010].



## **TECHNICAL GROUP**

### **CSLF Monitoring Geologic Storage for Commercial Projects Task Force**

### **Initial Compilation of Standards, Best Practices and Guidelines for CO<sub>2</sub> Storage and Monitoring**

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## CSLF IS GOING GREEN\*

### CSLF MONITORING GEOLOGIC STORAGE FOR COMMERCIAL PROJECTS TASK FORCE

### INITIAL COMPILATION OF STANDARDS, BEST PRACTICES AND GUIDELINES FOR CO<sub>2</sub> STORAGE AND MONITORING

*Note by the Secretariat*

#### Background

At the 4<sup>th</sup> CSLF Ministerial Meeting, at Beijing, China in September 2011, the Technical Group approved a new multi-year Action Plan. “Monitoring Geologic Storage for Commercial Projects” is one of the twelve Actions that comprise the Action Plan, and Norway is leading a new Task Force whose mission is to perform initial identification and review of new and updated standards for storage and monitoring of injected CO<sub>2</sub>. The planned scope of activities includes production of annual summaries of new as well as updated standards, guidelines and best practice documents regarding geological storage of CO<sub>2</sub> and monitoring of CO<sub>2</sub> sites. This report is an initial compilation of such standards, best practices, and guidelines.

#### Action Requested

The Technical Group is requested to review the Task Force’s report.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.

# Monitoring Geologic Storage for Commercial Projects Task Force

## Initial Compilation of Standards, Best Practices and Guidelines for CO<sub>2</sub> Storage and Monitoring

### Initial Draft

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## 1. Background

At the meeting of the CSLF technical Group in Bergen, Norway June 12, 2012, it was agreed that the new Task Force on “Monitoring of Geologic Storage for Commercial Projects” (TF6) should:

1. Identify and review existing standards for geological CO<sub>2</sub> storage and monitoring on an annual basis;
2. Identify and review existing guidelines for communication with and engagement of involved communities and regulators on an annual basis;
3. Identify shortcomings and/or weaknesses in standards/guidelines;
4. Communicate findings to the ISO CCS working group that has been established;
5. Produce annual summaries of new as well as updated standards, guidelines and best practice documents regarding geological storage of CO<sub>2</sub> and monitoring of CO<sub>2</sub> sites; and
6. Follow the work of other task forces related to CO<sub>2</sub> storage, e.g.:
  - a. Task Force on Action Plan #7 – Technical Challenges for Conversion of CO<sub>2</sub>-EOR to CCS (Chaired by Canada).
  - b. Task Force on Action Plan #1 – Technology Gap Closure (Chaired by Australia)

In the following the term CO<sub>2</sub> Capture, Utilization and Storage (CCUS) will be used instead of the more commonly used CO<sub>2</sub> Capture and Storage (CCS), which is used only when it occurs in the title of a document.

## 2. Scope of this note

This note concerns point 1 above and is the first draft of an initial compilation of standards, Best Practices Manuals (BPMs) and guidelines for geologic storage of CO<sub>2</sub>. Hereafter the term BPM is used for all three concepts. The purpose is to list relevant BPMs on CO<sub>2</sub> storage and give a very brief summary of the contents. Point 3 above, identifying shortcomings, as well as point 4, making proposals for improvements and communicate these to the ISO working group on CCS (ISO/TS/P 221), will be the topic of a later memo.

The note will list documents that relate to storage capacity estimation in Chapter 5 but will not go into details, as the topic may be treated by another Task Force.

Whether or not to include the second point above, related to regulatory issues, community engagement and communication, is still to be decided by the TF. Some BPMs concerned with these topics are listed in Chapter 6 but not discussed further.

This note is based on a summary by CO2CRC (2011), issued in March 2011. It summarizes the evaluations of that report, excluding documents that deal with regulatory and public engagement issues, and supplements it by brief reviews of documents issued after March 2011.

CO2CRC (2011) lists 15 BPMs or other sources for information on storage of CO<sub>2</sub> that were publicly released by early 2011, three unreleased BPMs and four additional references. Of the three unreleased by March 2011 one has later been published.

There exist much general literature (lessons learned, experiences etc) with content that may contribute to improving or supplementing best practices, standards etc. This literature is not included in this first overview but a selection of publications will be included in an update.

Of the 15 released BPMs ten concern technical aspects of CO<sub>2</sub> storage. These, along with some BPMs released after March 2011, will be discussed in Chapter 3. This chapter will also include some general references on experience from CO<sub>2</sub> storage projects. Chapter 4 will reference some BPMs related to storage capacity estimation, whereas Chapter 5 will just list the four BPMs included in CO2CRC (2011) that deal with regulatory or community engagement issues (the fifth reference in CO2CRC (2011) is a website). Chapter 6 contains an update on the work of ISO TS/P 221 Carbon capture and storage (CCS) and Chapter 7 gives an assessment of scope and content of the various BPMs and makes the first attempt to identify shortcomings. Additional information is given in Appendices A – G on issues that will either be treated in more detail in the next phase (Appendices B and C) or are outside the scope of TF6 (Appendices A and D – G).

A list of Task Force members can be found in Appendix H.

### **3. Identified standards, best practices manuals and guidelines for CO<sub>2</sub> storage**

CO2CRC (2011) lists ten references relating to technical issues on CO<sub>2</sub> storage, excluding documents related to capacity estimation. One of these references, CO2NET Work Package 7 Best Practice Review from 2004, is not included here due to its age and very limited scope. The remaining nine BPMs from CO2CRC (2011) are listed in Table 1, with content and comments based on CO2CRC (2011).

A list of BPMs, guidelines or standards released after publication of CO2CRC (2011) is given in Table 2. This list is probably not exhaustive and TF6 members are asked to supplement it.

Table 3 gives brief descriptions of BPMs that have been announced but, to the knowledge of the TF6 Chair, have not been published.

*Table 1. Most relevant best practice manuals listed in CO2CRC (2011), excluding those addressing regulatory and public engagement issues as well as those purely addressing capacity estimation. Sorted alphabetically by issuing organization and then chronologically. Comments are based on CO2CRC (2011).*

Date	Issued by	Title	Contents	Comment
2008	BGS	Best practice for the storage of CO <sub>2</sub> in saline aquifers ( <a href="http://nora.nerc.ac.uk/2959/">http://nora.nerc.ac.uk/2959/</a> )	First published in 2003. The latest version (2008) covers all aspects of storage in saline aquifers: <ul style="list-style-type: none"> <li>• Identifying ideal reservoir</li> <li>• Seal properties</li> <li>• Capacity estimation</li> <li>• Predictive flow modelling,</li> <li>• Geochemical and geomechanical site characterization</li> <li>• Operating the site</li> <li>• Cost estimation</li> <li>• Transport needs</li> <li>• Monitoring plan design</li> <li>• History matching based on monitoring data</li> <li>• Safety and risk assessment procedures.</li> </ul>	The information is presented through case studies of what was done and learned at 5 separate projects including Sleipner and Schwarze Pumpe.
Jan. 2009	CO <sub>2</sub> Capture Project (CCP)	A technical basis for carbon dioxide storage ( <a href="http://www.co2captureproject.org/co2_storage_technical_book.html">http://www.co2captureproject.org/co2_storage_technical_book.html</a> )	Covers: <ul style="list-style-type: none"> <li>• Background and site selection</li> <li>• Operation</li> <li>• Closure</li> <li>• Monitoring</li> <li>• Detailed guide for well construction and completion that contains discussions on materials and the factors that govern which you can use and when (a significant addition that this publication includes and others do not).</li> </ul> <p>The BPM covers, with enough detail to be considered beyond basic, a technical understanding of the aspects of CO<sub>2</sub> storage.</p>	Based on experiences from participating companies in CO <sub>2</sub> injection. Uses a large number of case studies, separated from the text as standalone examples, to illustrate how the advice given in each section was used in reality. It is a guide to developing a storage project.

Feb. 2010	DNV	Guideline for selection and qualification of sites and projects for geological storage of CO <sub>2</sub> ( <a href="http://www.dnv.com.au/binaries/CO2QUALSTORE_guideline_tcm162-412142.pdf">http://www.dnv.com.au/binaries/CO2QUALSTORE_guideline_tcm162-412142.pdf</a> )	A step by step guide to selecting a CO <sub>2</sub> storage site that covers <ul style="list-style-type: none"> <li>• Pre-feasibility stages of developing a screening plan</li> <li>• Data acquisition</li> <li>• Capacity estimation</li> <li>• Modeling and simulation</li> <li>• Risk assessment</li> <li>• Regulation</li> <li>• Operation and closure (but majority of the BPM is on site selection and characterization).</li> </ul>	Covers the many different aspects that need to be considered and provides best practice for accomplishing each step often providing deliverables that could be expected. However, although it must be assumed that the best practices are based on lessons-learned; there are few direct case studies or examples that are mentioned as proof of the success of the best practices provided.
Sept. 2004	LBNL (GEO-SEQ Project Team)	Geologic carbon dioxide sequestration: Site evaluation to implementation ( <a href="http://www.netl.doe.gov/technologies/carbon_seq/refshelf/GEO-SEQ_BestPract_Rev1-1.pdf">http://www.netl.doe.gov/technologies/carbon_seq/refshelf/GEO-SEQ_BestPract_Rev1-1.pdf</a> )	This manual covers <ul style="list-style-type: none"> <li>• A non-detailed discussion on capacity estimation. Also covers</li> <li>• A section dedicated to EOR.</li> <li>• Characterization of brine-formation sequestration.</li> <li>• Monitoring</li> <li>• Verification</li> <li>• Disposal of impure CO<sub>2</sub> streams</li> <li>• Modeling and simulation</li> </ul>	Does not cover the issues in breadth or detail and is fairly basic in general.
Jan. 2009	NETL	Best practices for: Monitoring, verification, and accounting of CO <sub>2</sub> stored in deep geologic formations ( <a href="http://www.netl.doe.gov/technologies/carbon_seq/refshelf/MVA_Document.pdf">http://www.netl.doe.gov/technologies/carbon_seq/refshelf/MVA_Document.pdf</a> )	Comprehensive BPM addressing the need for and requirements of a monitoring program at a CCS project. Covers: <ul style="list-style-type: none"> <li>• Atmospheric, near-surface, and subsurface monitoring</li> <li>• Simulation techniques</li> <li>• Geophysical techniques, geochemical techniques and crustal and surface techniques</li> <li>• Pre-operational, operational, and post-operational phases of monitoring</li> <li>• Discussion on possible regulatory requirements.</li> </ul>	Utilizes numerous case studies and international projects to address what has been achieved so far and what will be required in the future.

Sept. 2010	NETL	<p>Best practices for: Geologic storage formation classification: Understanding its importance and impacts on CCS opportunities in the United States</p> <p>(<a href="http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM_GeologicStorageClassification.pdf">http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM_GeologicStorageClassification.pdf</a>)</p>	<p>Written for the purpose of understanding and applying geology to a CCS project. Covers background on:</p> <ul style="list-style-type: none"> <li>• Geological terminology,</li> <li>• Rock types and how they fit into CCS and which are most suitable.</li> </ul> <p>As well as more technical issues including as different depositional environments and what each one means for CCS.</p>	<p>This BPM covers only a very specific topic: understanding how geology affects a CCS project.</p>
Nov. 2010	NETL	<p>Best practices for: Site screening, site selection, and initial characterization for storage of CO<sub>2</sub> in deep geologic formations</p> <p>(<a href="http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM-SiteScreening.pdf">http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM-SiteScreening.pdf</a>)</p>	<p>Relates specifically to the needs of a generic CCS project covering all possible opportunities and what is necessary to select and characterize a site.</p> <p>Covers</p> <ul style="list-style-type: none"> <li>• Identifying and developing all potential injection sites and requirements for each type (saline/depleted reservoir/coal)</li> <li>• Data analysis</li> <li>• Injection strategies</li> <li>• Model development and refinement</li> <li>• Capacity estimation and overall suitability analysis</li> <li>• Social and environmental considerations in developing and operating a site.</li> </ul>	<p>A 110 page comprehensive discussion of ‘what you need to know’ with regard to storage. It addresses this from a fundamental standpoint covering basic scientific understanding and only occasionally inserting application examples. It does not cover simulation, risk and monitoring to a technical level as there are separate BPMs published to cover these.</p>

2008	WRI	Guidelines for CCS ( <a href="http://pdf.wri.org/ccs_guidelines.pdf">http://pdf.wri.org/ccs_guidelines.pdf</a> )	Covers the entire CCS process (Capture, transport, storage). Storage topics addressed are Recommended guidelines for: <ul style="list-style-type: none"> <li>• MMV</li> <li>• Risk assessment</li> <li>• Financial Responsibility</li> <li>• Property rights and ownership</li> <li>• Site selection and characterization</li> <li>• Injection operations</li> <li>• Site closure</li> <li>• Post-closure</li> </ul>	Unable to achieve the same level of detail as other BPMs, more an overview of a theoretical project development and what proponents 'should' consider and do to be successful. It is best described as a dictionary of CCS project aspects as opposed to a BPM. That being said, it does not call itself directly a best practice manual.
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Table 2. Relevant best practice manuals published after the CO2CRC (2011) report (March 2011). Sorted alphabetically by issuing organization and then chronologically. Comments by Chair TF6.

Date	Issued by	Title	Contents	Comment
June 2011	DNV	CO2WELLS Guideline for the risk management of existing wells at CO <sub>2</sub> geological storage site ( <a href="http://www.dnv.com/industry/energy/segments/carbon_capture_storage/recommended_practice_guidelines/co2qualstore_co2wells/index.asp">http://www.dnv.com/industry/energy/segments/carbon_capture_storage/recommended_practice_guidelines/co2qualstore_co2wells/index.asp</a> )	Describes a transparent methodology to evaluate the integrity of wells, and risk-based procedure for re-qualification of wells for CO <sub>2</sub> -injection. Content includes: <ul style="list-style-type: none"> <li>• Well integrity risk <ul style="list-style-type: none"> <li>○ Risk assessment and risk criteria</li> <li>○ Identification, analyses and evaluation of well risks</li> <li>○ Communication</li> </ul> </li> <li>• Qualification of existing wells</li> <li>• Assess performance of and qualification of wells</li> </ul>	The guideline provides a tool for independent validation and verification. Contributes to build confidence among regulators and stakeholders in risk informed approaches to selection and management of storage sites.

April 2012	DNV	Geological Storage of Carbon Dioxide (DNV-RP-J203) ( <a href="http://www.dnv.com/news_events/news/2012/newcertificationframeworkforco2storage.asp">http://www.dnv.com/news_events/news/2012/newcertificationframeworkforco2storage.asp</a> )	This Recommended Practice (RP) is part of DNV's series of RPs. The main objective is to provide a systematic approach to the selection, qualification and management of geological CO <sub>2</sub> storage sites. It covers: <ul style="list-style-type: none"> <li>• Storage screening and appraisal</li> <li>• Permitting <ul style="list-style-type: none"> <li>○ Context and requirements</li> <li>○ Risk performance targets</li> <li>○ Storage and closure permits</li> </ul> </li> <li>• Risk management, assessment and treatment</li> <li>• Well qualification</li> </ul>	The RP incorporates and combines the guidance given in: <ul style="list-style-type: none"> <li>• CO2QUALSTORE</li> <li>• CO2WELLS</li> </ul> These two guidelines were the final deliverables from joint industry projects whereas this RP has been developed, and will be maintained, by DNV.
June 2012	DNV	Qualification Management for Geological Storage of CO <sub>2</sub> (DNV-DSS-402) ( <a href="http://www.dnv.com/news_events/news/2012/newcertificationframeworkforco2storage.asp">http://www.dnv.com/news_events/news/2012/newcertificationframeworkforco2storage.asp</a> )	This DNV Service Specification (DSS) provides a framework for the certification of geological storage sites for CO <sub>2</sub> . It covers: <ul style="list-style-type: none"> <li>• Principles for selection, qualification and management of geological storage sites for CO<sub>2</sub></li> <li>• Service overview (basically what services DNV can provide)</li> <li>• Examples of CO<sub>2</sub> storage certification documents</li> </ul>	Not really a BPM but a description of DNV's services within selection, qualification and management of geological storage sites. As such it provides some guidance for CO <sub>2</sub> storage project developers and other parties, but the most important document is DNV-Rp-J203.
March 2011	NETL	Risk analysis and simulation for geologic storage of CO <sub>2</sub> ( <a href="http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM_RiskAnalysisSimulation.pdf">http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM_RiskAnalysisSimulation.pdf</a> )	The BPM includes elements that are required for accurate simulation for risk: <ul style="list-style-type: none"> <li>• Fundamentals</li> <li>• Identification</li> <li>• Assessment (including quantifying) and characterization</li> <li>• Mitigation;</li> <li>• And for simulation the many different processes (thermal, chemical, biological, etc...).</li> </ul> The BPM also covers how risk plans and numerical simulations can be applied separately and together to a CCS project in order to handle the potential risks of a CCS site.	A generic publication that provides an understanding of what risk and numerical simulation is and why it is an essential aspect to CCS. This BPM was developed from the lessons learned at numerous projects run by the Regional Carbon Sequestration Partnership (RCSP).

April 2012	NETL	<p>Best practices for: Carbon Storage Systems and Well Management Activities (<a href="http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM-Carbon-Storage-Systems-and-Well-Mgt.pdf">http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM-Carbon-Storage-Systems-and-Well-Mgt.pdf</a>)</p>	<p>This BPM covers:</p> <ul style="list-style-type: none"> <li>• Assessment Initial Site characterization</li> <li>• Injection design</li> <li>• Project cost revisions</li> <li>• Permitting</li> <li>• Establishing site security and access</li> <li>• Well and facility layout</li> <li>• Well pad preparations</li> <li>• Well drilling</li> <li>• Formation evaluation</li> <li>• Well construction</li> <li>• Well testing</li> <li>• Suitability of well</li> <li>• Pre-injection baseline</li> <li>• Injection system completion</li> <li>• Injection</li> <li>• Post-injection operations, including well and site closure and MVA</li> </ul>	<p>Purpose: to share lessons learned regarding site-specific management activities for carbon storage well systems. Builds on the experiences of the RCSPs and the petroleum and other private industry.</p> <p>The BPM is part of NETL's series of BPMs for CCUS.</p>
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Table 3. Announced but unreleased best practice manuals on CO<sub>2</sub> storage. As of September 7, 2012.

Date	Issued by	Title	Contents	Comment
	IEA	Best Practice Manual developed through learnings from Weyburn project	<p>This BPM will be a key of the IEA's 11 year monitoring program at the Weyburn EOR injection and storage project. It will cover</p> <ul style="list-style-type: none"> <li>• Technical components (including site characterisation, monitoring and verification, wellbore integrity and performance assessment)</li> <li>• Policy components (including regulatory issues, public communication and outreach)</li> <li>• Business environment.</li> </ul> <p>This BPM was expected to be released in 2011.</p>	Will be less about specific details from the Weyburn-Midale sites and more about lessons that are broadly applicable to any CO <sub>2</sub> sequestration site
	IPACCO <sub>2</sub> /CSA Standards	CCS Standards Manual	<p>This new standard focuses on:</p> <ul style="list-style-type: none"> <li>• Management</li> <li>• Site selection</li> <li>• Risk management</li> <li>• Monitoring and verification</li> <li>• Well infrastructure</li> <li>• Closure and decommissioning</li> </ul>	IPAC CO <sub>2</sub> and CSA Standards are jointly developing a code of best practice standards for CCS to be submitted to the Canadian government. Once completed it will be the World's first implemented CCS standards guide. Public review period ended Dec. 27, 2011.

It is outside the scope of TF6 to dwell into CCUS legislation. However, it is deemed relevant to include a list of guidance documents or guidelines that have been published as annexes or similar to regulations on CO<sub>2</sub> storage. Such guidelines often have contents and structure that resemble standards. A selection of such guidelines is shown in Table 4. The relevant regulations and legislation is given in Appendix A.

The list in Table 4 is not exhaustive. More information on legal aspects of CCUS can be found at the general website of the Carbon Capture Legal Programme (CCLP) of the University College of London (UCL), <http://www.ucl.ac.uk/cclp/>, and more directly related to dedicated CCUS legislation <http://www.ucl.ac.uk/cclp/ccsdedleg.php>. The websites provide summarizations, analyses, and responses to global CCUS legislation and regulations. The CCLP offers both their own interpretation of the legal works as well as links to the legislation and links to position and discussion papers from other organizations. Along with the section dedicated to existing legislation, the CCLP provides several short-report style papers and presentations that address particular issues surrounding the workings of regulatory issues. Additionally, CCLP mentions also the status in selected Member States of the transposition of the EU CCS Directive (<http://www.ucl.ac.uk/cclp/ccseutransposition.php>).

Table 4. Guidelines included as annexes etc to regulations

Date	Issued by	Title	Contents	Comment
2005	Australian Government	Australian Guiding Principles for Carbon Dioxide Capture and Geological Storage (Guiding Principles) ( <a href="http://www.ret.gov.au/resources/Documents/ccs/CCS_Aust_Regulatory_Guiding_Principles.pdf">http://www.ret.gov.au/resources/Documents/ccs/CCS_Aust_Regulatory_Guiding_Principles.pdf</a> )	<p>The purpose of the Guiding Principles is to promote consistency in the development of a CCS regulatory framework across the Australian states and territories. The Guiding Principles address six areas of CCS activities:</p> <ol style="list-style-type: none"> <li>1. Assessment and approval processes</li> <li>2. Access and property rights</li> <li>3. Transportation issues</li> <li>4. Monitoring and verification</li> <li>5. Liability and post-closure responsibilities</li> <li>6. Financial issues</li> </ol> <p>The Guiding principles are non-binding.</p>	<p>The Australian Government has developed a regulatory framework for offshore CO<sub>2</sub> storage based on amendments to existing petroleum legislation. (See e.g. <a href="http://www.ucl.ac.uk/cclp/ccsoffnational-AUS.php#envregs">http://www.ucl.ac.uk/cclp/ccsoffnational-AUS.php#envregs</a>).</p> <p>Two sets of non-binding guidelines have been developed to promote a consistent approach to the application of CCS activities in Australia, including offshore storage activities. These guidelines are summarised briefly in the column to the left.</p>
2009	Australian Government	Environmental Guidelines for Carbon Dioxide Capture and Geological Storage - 2009 ( <a href="http://www.ephc.gov.au/sites/default/files/Climate_GL_Environmental_Guidelines_for_CCS_200905_0.pdf">http://www.ephc.gov.au/sites/default/files/Climate_GL_Environmental_Guidelines_for_CCS_200905_0.pdf</a> )	<p>Environmental Guidelines are non-binding but do provide some high level supplementary information on</p> <ol style="list-style-type: none"> <li>1. Environmental assessment of CCS activities</li> <li>2. Monitoring of injected GHG substances</li> <li>3. Site closure</li> <li>4. The need for co-ordination across jurisdictions.</li> </ol>	

2011	European Commission	<p>Guidance Document 1 CO<sub>2</sub> Storage Life Cycle Risk Management Framework (<a href="http://ec.europa.eu/clima/policies/lowcarbon/ccs/implementation/docs/gd1_en.pdf">http://ec.europa.eu/clima/policies/lowcarbon/ccs/implementation/docs/gd1_en.pdf</a>)</p> <p>Guidance Document 2 Characterisation of the Storage Complex, CO<sub>2</sub> Stream Composition, Monitoring and Corrective Measures (<a href="http://ec.europa.eu/clima/policies/lowcarbon/ccs/implementation/docs/gd2_en.pdf">http://ec.europa.eu/clima/policies/lowcarbon/ccs/implementation/docs/gd2_en.pdf</a>)</p>	<p>Of the four guidance documents Directive 2009/31/EC nos. 1 and 2 are relevant for this overview. The purpose of the Guidance Documents is to assist stakeholders to implement the Directive (so-called CCS Directive Guidance).</p> <p>Document 1 (GD1) addresses the overall framework for geological storage in the CCS Directive for the entire life cycle of geological CO<sub>2</sub> storage activities including</p> <ol style="list-style-type: none"> <li>1. The phases</li> <li>2. Main activities</li> <li>3. Major regulatory milestones.</li> <li>4. High-level approach to risk assessment and management</li> </ol> <p>Guidance Document 2 (GD2) builds on GD1 provides guidance on:</p> <ol style="list-style-type: none"> <li>1. Site selection;</li> <li>2. Composition of the CO<sub>2</sub> stream;</li> <li>3. Monitoring;</li> <li>4. Corrective measures.</li> </ol> <p>The Guidance documents are non- legally binding.</p>	<p>The European Commission has issued a directive, DIRECTIVE 2009/31/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the geological storage of carbon dioxide and amending. The directive has four guidance documents, on</p> <ol style="list-style-type: none"> <li>1. Risk management</li> <li>2. Characterization and monitoring</li> <li>3. Transfer of responsibility</li> <li>4. Financial security and mechanism</li> </ol>
June 2007	OSPAR Convention	<p>OSPAR Guidelines for Risk Assessment and Management of Storage of CO<sub>2</sub> Streams in Geological Formations (<a href="http://www.ucl.ac.uk/cclp/pdf/OSPAR2007-Annex-7.pdf">http://www.ucl.ac.uk/cclp/pdf/OSPAR2007-Annex-7.pdf</a>)</p>	<p>The Guidelines provide generic guidance for Contracting Parties when considering applications for permits to store CO<sub>2</sub> in geological formations under the seabed. The Guidelines have four Annexes, whereof Annex 1 – Framework for Risk Assessment and management of Storage of CO<sub>2</sub> Streams in Geological Formations (FRAM) – is relevant for this overview. It addresses:</p> <ol style="list-style-type: none"> <li>1. Problem formulation</li> <li>2. Site selection and characterisation</li> <li>3. Exposure assessment</li> <li>4. Effects assessment</li> <li>5. Risk characterization</li> <li>6. Risk management</li> </ol>	<p>The OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic has issued Decision 2007/2 on the Storage of Carbon Dioxide Streams in Geological Formations with Guidelines  (<a href="http://www.ucl.ac.uk/cclp/pdf/OSPAR2007-Annex-6.pdf">http://www.ucl.ac.uk/cclp/pdf/OSPAR2007-Annex-6.pdf</a>)</p>

August 2012	EPA (US Government)	Geologic Sequestration of Carbon Dioxide: Underground Injection Control (UIC) Program Class VI Well Project Plan Development Guidance <a href="http://water.epa.gov/type/groundwater/uic/class6/upload/epa816r11017.pdf">http://water.epa.gov/type/groundwater/uic/class6/upload/epa816r11017.pdf</a>	This document describes the required elements of each of the five plans prospective Class VI injection well owners and operators must submit with a permit application under the Class VI Rule requirements: <ul style="list-style-type: none"> <li>○ Area of Review and Corrective Action Plan,</li> <li>○ Testing and Monitoring Plan,</li> <li>○ Injection Well Plugging Plan,</li> <li>○ Post-Injection Site Care (PISC) and</li> <li>○ Site Closure Plan, and Emergency and Remedial Response Plan</li> </ul>	This is a basic and non-technical guidance document with some emphasis on corrective action plans and emergency and remedial response plans. It is adapted to the US regulation for Class VI Wells and therefore also has guidance on how to prepare plans that relate specifically to US regulations.
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## 4. Basic assessment of scope and content of identified BPMs on technical aspects of CO<sub>2</sub> storage

CO2CRC (2011) has assessed the scope and content of the BPMs listed in Table 1 with respect level of details for the following aspects: pre-feasibility, site selection, capacity estimation, simulation and modelling, construction, operation, closure, monitoring and verification, risk assessment, community consultation and regulation.

Table 5 repeats CO2CRC's assessment of the BPMs in Table 1 and supplements it with *suggested* assessment of the BPMs in Tables 2, 3 and 4 by the Chair of TF6. There is little information available for the BPMs in Table 4 and this marked with NA.

In line with the limitations in scope for TF6 Table 5 excludes capacity estimation, community consultation and regulation. We have also excluded the DNV DSS-402 Qualification management for geological storage of CO<sub>2</sub>, as it is not a BPM.

The following short names are used in Table 5, with reference to the table where descriptions of the BPMs can be found:

Short name used in Table 5	Full name	Found in table
CO2STORE	Best practice for the storage of CO <sub>2</sub> in saline aquifers	1
CCP	A technical basis for carbon dioxide storage	1
DNV CO2QUAL	Guideline for selection and qualification of sites and projects for geological storage of CO <sub>2</sub>	1
DNV CO2WELLS	CO2WELLS Guideline for the risk management of existing wells at CO <sub>2</sub> geological storage site	2
DNV RP-J203	Geological Storage of Carbon Dioxide (DNV-RP-J203)	2
LBNL/GEOSEQ	Geologic carbon dioxide sequestration: Site evaluation to implementation	1
NETL MVA	Best practices for: Monitoring, verification, and accounting of CO <sub>2</sub> stored in deep geologic formations	1
NETL GS	Best practices for: Geologic storage formation classification: Understanding its importance and impacts on CCS opportunities in the United States	1
NETL SS	Best practices for: Site screening, site selection, and initial characterization for storage of CO <sub>2</sub> in deep geologic formations	1
NETL RA	Risk analysis and simulation for geologic storage of CO <sub>2</sub> (	2
NETL WM	Best practices for: Carbon Storage Systems and Well Management Activities	2
WRI CCS	Guidelines for CCS	1
IEA Weyburn	Best Practice Manual developed through learnings from Weyburn project	3
IPACCO2/CSA	CCS Standards Manual	3
AU1	Australian Guiding Principles for Carbon Dioxide Capture and Geological Storage (Guiding Principles)	4
AU2	Environmental Guidelines for Carbon Dioxide Capture and Geological Storage – 2009	4
EC1	Guidance Document 1. CO <sub>2</sub> Storage Life Cycle Risk Management Framework	4
EC2	Guidance Document 2. Characterisation of the Storage Complex, CO <sub>2</sub> Stream Composition, Monitoring and Corrective Measures	4
OSPAR	OSPAR Guidelines for Risk Assessment and Management of Storage of CO <sub>2</sub> Streams in Geological Formations	4
EPA	Geologic Sequestration of Carbon Dioxide: Underground Injection Control (UIC) Program Class VI Well Project Plan Development Guidance	4

Table 5. Assessment of scope and content of BPMs listed in Tables 1 – 4. For BPMs listed in Table 1 the assessment is by CO2CRC (2011). For the other BPMs the assessment is by Chair of TF6 and is to be regarded as suggestions.

BPM	Pre-feasibility	Site selection	Simulation and modelling	Construction	Operation	Closure	Monitoring and verification	Risk assessment
CO2STORE	Basic	Technical	Technical	-	Basic	Detailed	Technical	Detailed
CCP	-	Basic	-	Detailed	Detailed	Basic	Technical	Basic
DNV CO2QUAL	Detailed	Detailed	Basic	-	Detailed	Detailed	Basic	Detailed
DNV CO2WELLS	-	Technical (existing wells)	-	-	-	-	-	Technical (existing wells)
DNV RP-J203	Basic	Detailed	Basic	Detailed (wells)	-	-	Detailed	Detailed
GEOSEQ	-	Basic	Basic	-	-	-	Detailed	-
NETL MVA	-	-	-	-	Technical	Technical	Technical	Basic
NETL GS	Technical	Technical	-	-	-	-	-	-
NETL SS	Basic	Detailed	Basic	-	-	-	-	Technical
NETL RA	-	-	Technical	-	-	-	-	Technical
NETL WM	-	-	-	Technical	Technical	Technical	-	-
WRI CCS	Basic	Detailed	Basic	Basic	Basic	Detailed	Detailed	Detailed
IEA Weyburn	NA	NA	NA	NA	NA	NA	NA	NA
IPACCO2/CSA	NA	NA	NA	NA	NA	NA	NA	NA
AU1	-	-	-	-	-	-	-	-
AU2	-	-	-	-	-	-	(Very) Basic	- (Env. risk very basic)
EC1	-	-	-	-	-	-	-	Detailed
EC2	-	Detailed	Basic	-	-	-	Detailed	- (only corrective part)
OSPAR	Basic	Basic	-	-	-	-	-	Basic
EPA	-	-	-	-	-	Basic	Basic	Basic

The following assessment grades have been used. Some BPM have limited cope and the assigned “grade” applies to the topic of the BPM.

-	Not covered specifically	Technical	Provides technical details of projects, generally comprehensive
Basic	Briefly covered in a generic way	NA	Information is not available
Detailed	Comprehensive discussion, generally generic		

Table 5 indicates that none of the identified documents cover all topics listed. It also shows that site selection, monitoring and verification and risk assessment are best covered by existing standards, BPMs or guidance documents. It is beyond the scope of this initial compilation to go into details regarding strengths, weaknesses and needs for additions or improvements of the documents listed in Tables 1 – 4, that will be Phase 2. However, as a prelude to the next phase of the work of CSLF Action Plan Task Force 6, Appendix B gives a preliminary and non-exhaustive list of monitoring tools used in operative storage projects (Table B.1) and planned used in CO<sub>2</sub> projects under development (Table B.2) selection of risk assessment approaches, respectively.

Appendix C gives an overview of some risk assessment (RA) methodologies. These are generally classified in two main groups: qualitative and quantitative. Qualitative RA does not provide concrete or numerical results. Most common qualitative methods are the features, events, and processes (FEP), and the Vulnerability Evaluation Framework (VEF). The quantitative methods are used in well-known systems where the level of uncertainty is relatively low. Two main kinds of methods belong to this group: Deterministic Risk Assessment (DRA) and Probabilistic Risk Assessment (PRA). Table C.1 summarises some methods for RA.

## 5. Other related documents

It may be useful to have a picture of the storage capacity for CO<sub>2</sub> in different regions of the world. Appendix D lists some relevant documents and related references. The list is a combination of atlases and GIS (geodatabases and tools). Each of them bears specificity due to regional coverage (e.g. South Africa, Brazil) but also methodology (e.g. BGR, ETI, Caprock Italy). The references may not lead to the document or database itself but to a website where more information may be found

Community consultation and engagement is important to achieve understanding of CCUS has a greenhouse gas mitigating option. Appendix E lists some BPMs related to the topic. These will not be pursued further until a decision has been made on whether or not this is the responsibility of the CSLF TG. Comments are by CO2CRC (2011).

Storage capacity estimation is part of the CCUS chain and falls under storage. However, a separate Task Force on the subject may be proposed under CSLF TG Action Plan. Appendix G lists some relevant BPMs or related documents but these will not be treated further until the fate of a separate TF has been decided.

Pipelines are outside the scope for TF6 but some standards, BPMs and guidance documents are shown in Appendix G as it was suggested to include this.

## 6.ISO/TS/P 221 Carbon capture and storage (CCS)

TF6 shall establish communication with the ISO working group on CCS. This chapter will be updated as interface develops.

## 7. References

CO2CRC (2011) A review of best practice manuals for carbon dioxide storage and regulation. <http://www.globalccsinstitute.com/publications/review-existing-best-practice-manuals-carbon-dioxide-storage-and-regulation>

## Appendix A. Regulations

Table A.1. Legislation and regulations to which the guidelines of Chapter 3, table 4, are associated. Comments are not provided, as legislation is outside the scope for Task Force 6 “Monitoring of Geologic Storage for Commercial Projects”.

Date	Issued by	Title
2008 - 2011	Australian Government	Offshore Petroleum Amendment (Greenhouse Gas Storage) Act 2008 (OPGGS Act); Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2009; Offshore Petroleum and Greenhouse Gas Storage (Management of Greenhouse Gas Well Operations) Regulations 2010; Offshore Petroleum and Greenhouse Gas Storage (Management of Greenhouse Gas Well Operations) Regulations 2010; Offshore Petroleum and Greenhouse Gas Storage (Resource Management and Administration) Regulations 2011 (RMA Regs); Offshore Petroleum and Greenhouse Gas Storage (Injection and Storage) Regulations 2010 (Draft), see also <a href="http://www.ucl.ac.uk/cclp/ccsdedlegnat-AUS.php">http://www.ucl.ac.uk/cclp/ccsdedlegnat-AUS.php</a> .
Dec. 2010	Alberta, Canada	Carbon Capture and Storage Statutes Amendments Act 2010, see also <a href="http://www.ucl.ac.uk/cclp/ccsdedlegnat-CAN.php">http://www.ucl.ac.uk/cclp/ccsdedlegnat-CAN.php</a>
April 2009	European Commission	DIRECTIVE 2009/31/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL ( <a href="http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0114:0135:EN:PDF">http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0114:0135:EN:PDF</a> )
June 2007	OSPAR Convention	OSPAR Decision 2007/2 on the Storage of Carbon Dioxide Streams in Geological Formations ( <a href="http://www.ucl.ac.uk/cclp/pdf/OSPAR2007-Annex-6.pdf">http://www.ucl.ac.uk/cclp/pdf/OSPAR2007-Annex-6.pdf</a> ); ( <a href="http://www.ucl.ac.uk/cclp/ccsoffeuropespar.php">http://www.ucl.ac.uk/cclp/ccsoffeuropespar.php</a> ) ( <a href="http://www.ucl.ac.uk/cclp/pdf/OSPAR_Convention_e_updated_text_2007.pdf">http://www.ucl.ac.uk/cclp/pdf/OSPAR_Convention_e_updated_text_2007.pdf</a> ); 8 <a href="http://www.ucl.ac.uk/cclp/pdf/OSPAR2007-Annex-5.pdf">http://www.ucl.ac.uk/cclp/pdf/OSPAR2007-Annex-5.pdf</a> )
2008	UK	Energy Act 2008 ( <a href="http://www.legislation.gov.uk/ukpga/2008/32/pdfs/ukpga_20080032_en.pdf">http://www.legislation.gov.uk/ukpga/2008/32/pdfs/ukpga_20080032_en.pdf</a> ). See also <a href="http://www.ucl.ac.uk/cclp/ccsdedlegnat-UK.php">www.ucl.ac.uk/cclp/ccsdedlegnat-UK.php</a>
July 2008	EPA (US Government)	<a href="http://www.ucl.ac.uk/cclp/ccsdedlegnat-US-Federal.php">Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO<sub>2</sub>) Geologic Sequestration (GS) Wells</a> ; see also <a href="http://www.ucl.ac.uk/cclp/ccsdedlegnat-US-Federal.php">http://www.ucl.ac.uk/cclp/ccsdedlegnat-US-Federal.php</a>
Dec. 2010	EPA (US Government)	Final rule for Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO <sub>2</sub> ) Geologic Sequestration (GS) Wells ( <a href="http://water.epa.gov/type/groundwater/uic/class6/gsregulations.cfm">http://water.epa.gov/type/groundwater/uic/class6/gsregulations.cfm</a> )

## Appendix B. Monitoring tools and techniques used in some projects

Table B.1. Monitoring technologies used at some present storage sites. The list is based on the references supplemented by Myer (2011) and should not be regarded as complete. Supplemented by information from Jones and Chadwick (2012).

	Site					
	Sleipner <sup>1</sup>	Weyburn <sup>2</sup>	In Salah <sup>3</sup>	Snøhvit <sup>4</sup>	Otway <sup>5</sup>	Ketzin <sup>6</sup>
Seismic	x	x	x	x	x	x
Electrical (EM, ERT)	x					x
Gravity	x					
Tiltmeters			x			
Downhole P, T			x	x	x	x
Acoustic (echo sounder, sonar)	x					
Soil gas		x	x		x	x
Microseismic (passive seismic)	x	x	x		x	x
Observation wells		x	x		x	x
Tracers		x	x			x
Microbiology			x			x
Wireline logs			x			x
Fluid samples		x			x	x
Atmospheric CO <sub>2</sub>					xx	

<sup>1</sup> CO2STORE (2006); <sup>2</sup> Wilson and Monea, (2005); <sup>3</sup> (Mathieson et al., 2010; Wright et al., 2010); <sup>4</sup> Myer (2011); <sup>5</sup> CO2CRC (2012); <sup>6</sup> Würdemann et al. (2010)

Table B.2. Monitoring technologies used at storage sites under development (October 2012)

	Site				
	Quest	Gorgon	<u>Illinois Basin-Decatur Project</u>	Boundary Dam (EOR)	Kemper County (EOR)
Seismic					
Electrical (EM, ERT)					
Gravity					
Tiltmeters					
Downhole P, T					
Acoustic (echo sounder, sonar)					
Soil gas					
Microseismic (passive seismic)					
Observation wells					
Tracers					
Microbiology					
Wireline logs					
Fluid samples					
Atmospheric CO <sub>2</sub>					

## Appendix C. Risk Assessment (RA)

Table C.2. Some methodologies for risk assessment of geological storage of CO<sub>2</sub> (Condor et al., Energy Procedia 4(2011) 4036-4043)

Method	Goal	Data needed	Industrial application	Application for GSC
DRA	Analytical point estimate calculations	Numerical and qualitative expert estimation for scenario development and model development	Safety engineering (sensitivity analysis)	Initial risk assessment. No uncertainty estimations
PRA	Predict the probability of safety failures of complex system	Numerical qualitative expert estimation for scenario development, model development quantifying PDFs	Safety engineering	Detailed risk assessment. Uncertainty estimation
FEP	Scenario development	Qualitative expert estimation for scenario development	Scenario analysis	Screening and Site selection
VEF	Conceptual framework for regulators and technical experts	Qualitative expert estimation to identify which areas should be in-depth studied	Hazard identification and potential consequences	Framework for site selection and regulator guidance
SWIFT	Elaborate hypothesis	Qualitative expert estimation to identify hazards	Hazard identification in engineering	Hazard and consequence mapping
MCA/MAUT	Evaluation of alternatives in multiple objective	Qualitative and numerical expert estimation for data input utility	Decision making	Framework for screening and site selection
RISQUE	Systemic process with participation of expert panels estimation in event-tree approach	Qualitative and numerical expert	Hazard identification and potential consequences	Hazard and consequence mapping
CFA/SRF	Estimation of risk based on probabilities of occurrence in individual features	Qualitative and quantitative estimation of risk and uncertainty	Development of simple probabilistic models	Managing risks in GSC sites
MOSAR	Identifying and preventing risks	Qualitative and quantitative data for a well-known system	Risk reduction in complex systems	Systematic risk analysis for well-known sites
ESL	Identification of uncertainties in decisions	Qualitative and quantitative understanding of uncertainties	Reduction of uncertainties in well-known systems	Detailed PRA and dealing with uncertainties
P&R	Risk mapping in wellbores under the criteria of degradation scenarios	Qualitative and quantitative data for wellbores	Risk evaluation under the concept of ALARP	Long-term well integrity
SMA	Estimation of risk based on probabilities.	Quantitative estimation of risk and PDFs	Development of complex models in well-known systems	PRA for the whole CCS chain

## Appendix D. Selection of CO<sub>2</sub> Storage Atlases

This list is a combination of Atlases and GIS (geodatabases and tools). Each of them bears specificity due to regional coverage (e.g. South Africa, Brazil) but also methodology (e.g. BGR, ETI, Caprock Italy).

Carbon Sequestration Atlas of the United States and Canada I, II and III

([http://www.netl.doe.gov/technologies/carbon\\_seq/refshelf/atlasIII/index.html](http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasIII/index.html))

The North American Carbon Storage Atlas 2012

([http://www.netl.doe.gov/technologies/carbon\\_seq/refshelf/NACSA2012.pdf](http://www.netl.doe.gov/technologies/carbon_seq/refshelf/NACSA2012.pdf))

The CO<sub>2</sub> Storage Atlas Norwegian North Sea 2011

(<http://www.npd.no/Global/Norsk/3-Publikasjoner/Rapporter/PDF/CO2-ATLAS-lav.pdf> )

Queensland carbon dioxide geological storage atlas. Compiled by Greenhouse Gas Storage Solutions on behalf of Queensland Department of Employment, Economic Development and Innovation.

([http://www.cgss.com.au/Assesment%20of%20Qlds%20CO2%20geological%20storage%20prospectivity\\_web%20version.pdf](http://www.cgss.com.au/Assesment%20of%20Qlds%20CO2%20geological%20storage%20prospectivity_web%20version.pdf))

South Africa CO<sub>2</sub> Storage Atlas (<http://www.sacccs.org.za/wp-content/uploads/2010/11/Atlas.pdf>)

BGR Germany CO<sub>2</sub> Storage "Atlas" (GIS)

([http://www.bgr.bund.de/DE/Themen/CO2Speicherung/Downloads/Speicherkataster\\_Kartenanwendung.html](http://www.bgr.bund.de/DE/Themen/CO2Speicherung/Downloads/Speicherkataster_Kartenanwendung.html)). Description in:

[http://www.bgr.bund.de/DE/Themen/CO2Speicherung/Downloads/Speicherkataster\\_synthese.pdf?\\_\\_blob=publicationFile&v=4](http://www.bgr.bund.de/DE/Themen/CO2Speicherung/Downloads/Speicherkataster_synthese.pdf?__blob=publicationFile&v=4);

[http://www.bgr.bund.de/DE/Themen/CO2Speicherung/Downloads/Speicherkataster\\_Nachweissystem.pdf?\\_\\_blob=publicationFile&v=1](http://www.bgr.bund.de/DE/Themen/CO2Speicherung/Downloads/Speicherkataster_Nachweissystem.pdf?__blob=publicationFile&v=1) )

ETI UK SAP (GIS)

The Brazilian Carbon Geological Sequestration Map (CARBMAP Project, some info at [http://www.pucrs.br/cepac/index\\_e.php?p=programas](http://www.pucrs.br/cepac/index_e.php?p=programas))

The geo-database of caprock quality and deep saline aquifers distribution for geological storage of CO<sub>2</sub> in Italy (GIS)

(<http://www.sciencedirect.com/science/article/pii/S036054421100137X>)

## Appendix E. BPMs on regulatory issues, community engagement and communication

Table E.1. Best practices etc. that considers regulatory issues, community engagement and similar (based on CO2CRC, 2011)

Date	Issued by	Title	Contents	Comment
Nov. 2010	CCP	Update on Selected Regulation Issues for CO <sub>2</sub> Capture and Geological Storage ( <a href="http://www.co2captureproject.org/reports/regulatory_report.pdf">http://www.co2captureproject.org/reports/regulatory_report.pdf</a> )	Covers the following sections <ul style="list-style-type: none"> <li>• Carbon capture readiness</li> <li>• permitting and licensing,</li> <li>• impurities in injected CO<sub>2</sub> streams</li> <li>• pore space ownership,</li> <li>• liability issues</li> <li>• Monitoring, reporting and verification requirements</li> </ul> Each section has a general overview followed by a country by country description of how some nations handle the particular issue.	Dedicated to understanding regulation, this manual is structured by regulatory subject. Although it does not cover as many issues as the IEA framework, the inclusion of thorough reviews of existing legislation on key issues merits regarding this BPM as a valuable resource.
Nov. 2010	IEA	CCS Model Regulatory Framework ( <a href="http://www.iea.org/ccs/legal/model_framework.pdf">http://www.iea.org/ccs/legal/model_framework.pdf</a> )	Covers <ul style="list-style-type: none"> <li>• the entire CCS chain from capture through to storage site closure and provides a comprehensive discussion of the issues regulators face</li> <li>• reporting and classification issues, liability, hazards and risk, inspections and monitoring, financial aspects</li> <li>• areas that need to be standardized such as fluid composition.</li> </ul>	This framework provides a guideline for understanding what must go into developing regulations for CCS. It uses existing regulations as examples of how the guidelines proposed have been used. Although, focused on only one aspect of storage (regulation) it does so thoroughly.
Dec. 2009.	NETL	Best Practices for: Public outreach and education for carbon storage projects ( <a href="http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM_PublicOutreach.pdf">http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM_PublicOutreach.pdf</a> )	This BPM covers <ul style="list-style-type: none"> <li>• The importance of public outreach</li> <li>• How public outreach should be integrated into the development of the project</li> <li>• Identifying stakeholders, an information gathering practice termed 'social characterization</li> <li>• Developing plans and strategies,</li> <li>• Clarification on what key messages should be and how to tailor them to a public audience.</li> </ul>	This BPM takes the short social outreach discussion from the site screening BPM and expands it using a generic approach combining lessons learned from numerous projects in a non-specific way.

Oct. 2010	WRI	Guidelines for community engagement in CCS ( <a href="http://pdf.wri.org/ccs_and_community_engagement.pdf">http://pdf.wri.org/ccs_and_community_engagement.pdf</a> )	Includes understanding <ul style="list-style-type: none"> <li>• The importance of community engagement</li> <li>• The needs of different stakeholders</li> <li>• of applying community engagement to the specifics of CCS throughout the entire life of a project</li> <li>• Of how to cover impacts and risks effectively and what reactions to expect</li> <li>• The best practice for presenting and exchanging information.</li> </ul>	Comprehensive review of the CCS community engagement process. Provides numerous examples from around the world of the case studies where these lessons were learned.
2010	USGS	A probabilistic assessment methodology for the evaluation of geologic carbon dioxide storage: U.S. Geological Survey Open-File Report 2010-1127, 31 p., ( <a href="http://pubs.usgs.gov/of/2010/1127">http://pubs.usgs.gov/of/2010/1127</a> )		

## Appendix F. BPMs on CO<sub>2</sub> storage capacity

Table F.1. Best practices and similar that relates to capacity estimation

Date	Issued by	Title	Contents	Comment
March 2003	Stefan Bachu	Screening and Ranking of sedimentary basins for sequestration of CO <sub>2</sub> ( <a href="http://www.geology.wmich.edu/bachu_Barnes_2003.pdf">http://www.geology.wmich.edu/bachu_Barnes_2003.pdf</a> )  Screening and Ranking of hydrocarbon reservoirs for CO <sub>2</sub> storage ( <a href="http://www.netl.doe.gov/publications/proceedings/01/carbon_seq/p21.pdf">http://www.netl.doe.gov/publications/proceedings/01/carbon_seq/p21.pdf</a> )		Some of the first articles on the subject of site selection for CO <sub>2</sub> storage. The subject matter is very broad and applied to regional scale assessment but nonetheless represents one of the first thorough attempts to provide a guide and understanding to CCS site screening.
March 2008	CO2CRC	Storage Capacity Estimation, Site Selection and Characterisation for CO <sub>2</sub> Storage Projects ( <a href="http://www.ukerc.ac.uk/support/tiki-download_file.php?fileId=2395">http://www.ukerc.ac.uk/support/tiki-download_file.php?fileId=2395</a> )		A comprehensive, although generic, report on what is necessary to select and characterize a site and assess the storage capacity. We have not considered this a best practice manual because, although it provides a thorough and valuable resource on site selection, it is presented as more of a ‘what to consider’ as opposed to what practices should be undertaken.
2005, 2007 and 2008	CSLF Task Force for Review and Identification of Standards for CO <sub>2</sub> Storage Capacity	Measurement, Phase I, II and III ( <a href="http://www.cslforum.org/publications/index.html?cid=nav_publications">http://www.cslforum.org/publications/index.html?cid=nav_publications</a> )		
	NETL	Methodology for Development of Geologic Storage Estimates for Carbon Dioxide ( <a href="http://www.netl.doe.gov/technologies/carbon_seq/refshelf/methodology2008.pdf">http://www.netl.doe.gov/technologies/carbon_seq/refshelf/methodology2008.pdf</a> )		Although this could be considered a BPM, presented as a technical guide to storage capacity estimation, it is included as an additional reference due to its limited scope and the fact that it has been superseded by NETL’s site screening BPM which contains a technical section on storage capacity.

2010	CHINA(country based not BPM)	Chinese methodologies of storage capacity estimation. Near-term mega-scale CO2 capture and storage demonstration opportunities in China Zheng et. al., 2010. doi:10.1016/j.fuel.2011.07.004		
2011	JAPAN (country based not BPM)	Japanese methodology of storage capacity estimation. Saline-aquifer CO2 sequestration in Japan-methodology of storage capacity assessment. Ogawa et al., 2011. http://dx.doi.org/10.1016/j.ijggc.2010.09.009	National onshore and offshore assessment for Japan	A nationwide saline-aquifer CO2 storage capacity assessment carried out in Japan.  The multiplication of $S_f$ and $S_g$ is analogous to efficiency factor in US DOE methodology and Capacity coefficient of CSLF methodology ranges from 1% to 20%
Others *	UK (country based not BPM)	UK CO2 Storage Appraisal Project (ETI 2011)	National offshore resource estimate for UK	Estimate of the storage resource that is theoretically accessible without recourse to pressure management and chase water injection. Chances of success and economics of each storage unit assessed.
	DE (country based not BPM) ( <a href="http://www.bgr.bund.de/DE/Themen/CO2Speicherung/Downloads/Speicherkataster_Kartenanwendung.html">http://www.bgr.bund.de/DE/Themen/CO2Speicherung/Downloads/Speicherkataster_Kartenanwendung.html</a> )	GIS-basierte Kartenanwendung „Informationssystem Speicher-Kataster Deutschland“ (ArcReader 10 erforderlich, issued by BGR	Regional capacity assessment onshore and offshore for Germany	Capacity in structural and stratigraphic traps estimated. GIS/Spreadsheet

\*source S. Holloway (IEA Seminar 2011). Please note also ongoing efforts towards a common methodology worldwide for CO2 Storage Capacity Assessment – S. Brennan et al, 2011. GHG 11 Abstract. Towards international guidelines for CO2 storage capacity estimation.

## Appendix G. BPMs and current guidance and standards conveying CO<sub>2</sub> in pipelines in connection with CCS projects

Table G.1. Some standards, BMPs and guidelines related to CO<sub>2</sub> transport in pipelines

Date	Issued by	Title	Contents
ALARP	HSE (UK)	Reducing risk As Low As Reasonably Practicable <a href="http://www.hse.gov.uk/pipelines/co2conveying.htm#a9">http://www.hse.gov.uk/pipelines/co2conveying.htm#a9</a>	Application of good practice at the design stage is essential to demonstrating reduction of (ALARP). HSE expects duty holders to apply relevant good practice. Depending on the level of risk and complexity involved, it is possible the adoption of good practice alone may not be sufficient to comply with the law.
1996	PSR	Pipelines Safety Regulations	<p>Regulation 5 requires that the design of a pipeline, or any modification to it, takes account of the operating regime of the pipeline and the conditions under which the fluid is to be conveyed as well as the environment to which the pipeline will be subjected. In particular with regard to the re-use of existing pipelines, any proposal to change the fluid conveyed will require a re-assessment of the original pipeline design to ensure that the pipeline is capable of conveying the fluid safely.</p> <p>European Standards implemented in the UK as British Normative Standards (BS EN series) and supported by published documents (such as the British Standards PD series) provide a sound basis for the design of pipelines. Other national or international codes e.g. a relevant standard or code of practice of a national standards body or equivalent body of any member state of the European Union are likely to be acceptable provided the proposed standard, code of practice, technical specification or procedure provides equivalent levels of safety.</p>
	European Standards	PD 8010: 2004; BS EN 14161: 2003; Institute of Petroleum Pipeline Code IP6; DNV OS-F101 - Submarine Pipeline Systems (2007)	Codes IP6, BS EN 14161, BS PD 8010 and DNV OS-F101 are all applicable to pipelines transporting CO <sub>2</sub> ; the last three categorising it as a non- flammable, non-toxic fluid which is gaseous at ambient temperature and pressure. IP6 also treats CO <sub>2</sub> as a gas.

	US Pipeline Codes	US Federal Code of Regulations, Title 49, Volume 3, Part 195 – Transportation of Hazardous Liquids by Pipeline and the associated ASME standards B31.4 and B31.8	<p>Main American codes which address the transportation of liquids and gases by pipeline respectively.</p> <p>The US Federal Code only applies to pipelines transporting CO2 in the supercritical phase and is therefore only relevant to proposals to use pipelines to convey supercritical CO2. There does not appear to be any equivalent code which addresses the transport of gaseous or liquid CO2.</p>
April 2010	DNV	Recommended Practice DNV-RP-J202. Design and operation of CO2 pipelines	<p>The Recommended Practice (RP) was developed to address the need for guidance for how to manage risks and uncertainties specifically related to transportation of CO2 in pipelines.</p> <p>The document provides guidance and sets out criteria for the concept development, design, construction and operation of steel pipelines for the transportation of CO2. It is written to be a supplement to existing pipeline standards and is applicable to both onshore and offshore pipelines. The RP is intended to assist in delivering pipelines in compliance with international laws and regulations. The pipeline operator will also have to ensure that the project is in compliance with local laws and regulations.</p>

## Appendix H. Task Force Members

Family Name	Given Name	Country	Affiliation	e-mail
Arts	Rob	Netherlands	TNO, the Netherlands	rob.arts@tno.nl
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## **TECHNICAL GROUP**

### **CSLF Closing the Technology Gaps Task Force**

#### **Discussion Note on Content, Scope and Process**

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## CSLF IS GOING GREEN\*

### CSLF CLOSING THE TECHNOLOGY GAPS TASK FORCE DISCUSSION NOTE ON CONTENT, SCOPE AND PROCESS

*Note by the Secretariat*

#### Background

At the 4<sup>th</sup> CSLF Ministerial Meeting, at Beijing, China in September 2011, the Technical Group approved a new multi-year Action Plan. “Technical Gaps Closure” is one of the twelve Actions that comprise the Action Plan, and Australia is leading a new Task Force that is focusing on identification and review of new updated critical technology gaps and opportunities for CO<sub>2</sub> capture transport, storage, and environmental monitoring and verification. This paper is an initial report from the Task Force Chair, Richard Aldous.

#### Action Requested

The Technical Group is requested to review the Task Force’s report.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.

# CSLF Closing the Technology Gaps Task Force

## Discussion Note on Content, Scope and Process

### Background

The meeting of the CSLF Technical Group (TG) in Bergen on June 12, 2012, confirmed the concept of a Closing the Technology Gaps Task Force (CTGTF). It was agreed that the task force would consist of the following members Australia, Korea, Norway, and the United States. The focus of the task force would be as set out in the documentation for that meeting (see Appendix 1). Names and contact details of the members representatives are as follows:

Australia - Richard Aldous ([richard.aldous@co2crc.com.au](mailto:richard.aldous@co2crc.com.au))

USA - Darren Mollot ([darren.mollot@hq.doe.gov](mailto:darren.mollot@hq.doe.gov))

Korea - Chang-Keun Yi ([ckyi@kier.re.kr](mailto:ckyi@kier.re.kr))

Norway - Lars Ingolf Eide ([lie@rcn.no](mailto:lie@rcn.no))

At the same meeting it was decided to revise the CSLF's Technology Roadmap (TRM) with a view to producing a short and concise document with focus on technological priorities and recommendations to policy and decision makers. The focus of this is to be on technology developments that are needed to enable large-scale deployment.

The proposed work of the CTGTF will be to undertake a comprehensive view of the key technologies in play around carbon capture and storage (CCS) and carbon capture, utilization and storage (CCUS) with a view to identify scientific and technology gaps and opportunities which have potential to significantly impact on CCS/CCUS demonstration and deployment. It is expected that this will inform the high level TRM and be a complementary document. Both documents are planned to be finalized for the Ministerial meeting scheduled for the fall of 2013.

The CTGTF will be responsible for the analysis and documentation of the technology gaps and opportunities.

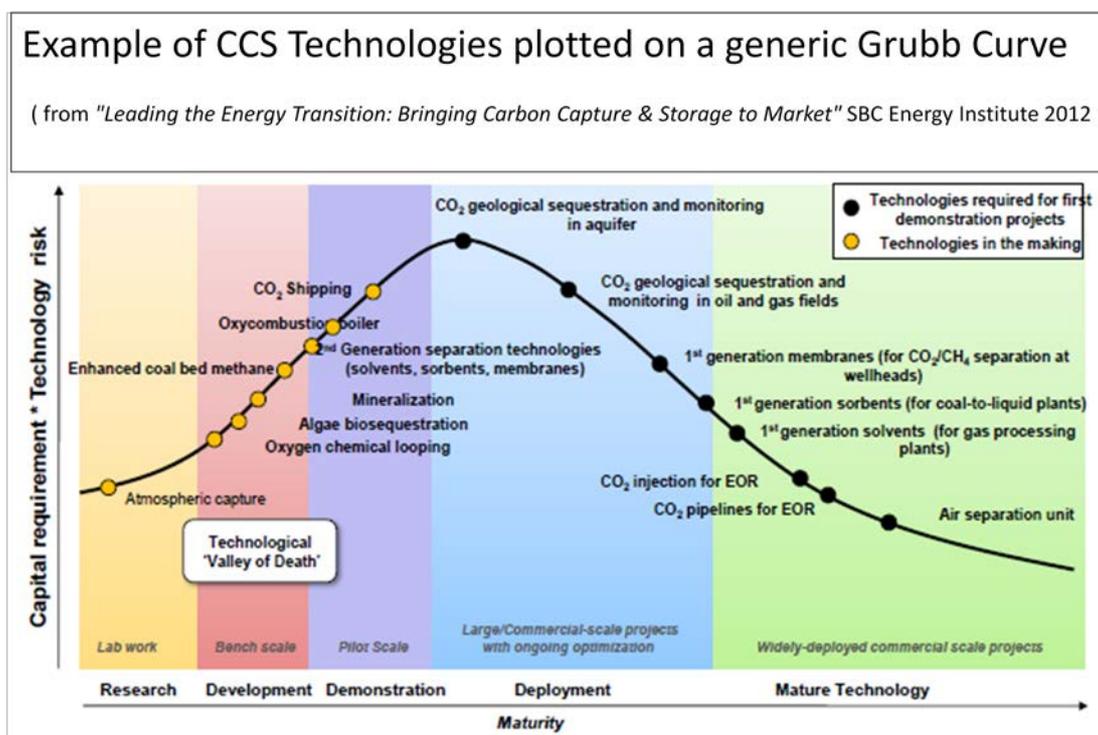
This document sets out for discussion and information a proposed methodology and approach for the CTGTF to follow in gathering and assessing information on technologies. It also provides a draft of the document structure envisaged for the final product.

### Proposed Methodology

The project is proposed to be an assessment of the status of technologies in CCS/CCUS with respect to their state of development and likely pathways going forward. Emphasis will be on technologies that are deemed likely to become commercial before 2030, but with a view to technologies emerging towards 2050.

It is proposed to:

- Prepare a table of all major technologies.
- Grade the technologies according to their state of development. The exact methodology for assessing the technologies as yet to be agreed but one option is a simple assessment of whether technologies are at laboratory scale, pilot scale, or at large scale demonstration stage with optimisation upside. Another option is a simplified version of the NASA system of technology readiness.
- Technologies will be plotted on a generic Grubb curve (see example below).
- Assess and comment on their likely development pathway and the costs required to get to large scale demonstration or into commercial use.
- Set out who is the owner of the technology.
- Rank technologies in terms of international urgency/ necessity to progress the technology because of its potential impact on effective low cost CCUS deployment (High / Medium / Low).
- General comments.



## Draft high level structure of the CTG Document

The following outline is proposed for the final report.

1. Executive Summary
2. Introduction: Objectives and Scope

Why is it important to have a review of the technologies in CCUS.

The objective is to have an assessment of all the major technologies in CCS

- a. What is the current status of CCUS technology?
- b. Where are the technologies on the generic Grubb curve?
- c. Where will the technologies be in 2020-2030 (and possibly in 2050)?
- d. What are the recommendations on technologies with great promise and gaps in the technology landscape?

This can be used to guide governments in prioritizing their support for technology activities relating to the early and successful implementation of CCUS.

### **3. Methodology for assessing status of technologies**

A description of the methodology used in the analysis. For example, spreadsheet of all technologies, international network of technologists having input into identifying and grading technologies. The use of assessment and presentation tools, e.g., Grubb Curves, NASA technology readiness system, etc.

### **4. Assessment of present situation**

What are the major categories of technologies and how do they fit together. What is their role on the deployment of CCS technologies? Who is doing the work and how will it propagate internationally, i.e., what is the likely deployment and commercialisation pathway.

### **5. Analysis of the data**

This section will draw out the key findings of the study.

The technologies that:

- a) are established and will keep developing /improving;
- b) can make a difference but which are still on the development pathway;
- c) possible breakthrough areas to watch; and
- d) promising technologies without a good development pathway or owner.

These will be discussed under each of the following headings:

- Capture
- Transport
- Subsurface
- MMV

### **6. Prioritized technology related RD&D activities**

### **7. Recommendations for implementation**

This section will focus on recommendations for technology implementation, and global collaboration and how we get more out of the global R&D portfolio. Given the opportunities and gaps, recommendations will be made to CSLF governments.

**Appendices:** These will include a spreadsheet of all technologies considered.

## The process and timeline

The process will be divided into the following phases and tasks:

Task 1: Agreement by the task force steering committee on this discussion document, including the Scope and Table of Contents. Review and finalisation **at or before the meeting in Perth in October 2012**.

Task 2: Agreement on the methodology and division of work. **December 2012**  
This may take more time and will follow the CSLF meeting in Perth on October 24-26, 2012. This task also includes allocation of resources necessary to perform the work with the TRM.

Task 3: Collection, collation and analysis of data. **March 2013**  
This phase could include the following activities:

- a. Phone hook ups and integration of data
- b. Prepare status and assessment – CO<sub>2</sub> capture, storage, utilisation, transport, and MMV
- c. Prepare recommendations for implementation
- c. Prepare draft report

In parallel to the above the task force will be feeding information to the TRM Process, surface ideas and technological trends that could be considered in the TRM.

Task 4: Approval. **July 2013**

This phase could include the following activities:

- a. Hearing round with critique, comments and validation by CSLF TG members
- b. Revision
- c. Approval at Ministerial meeting fall 2013.

# APPENDIX 1

## CSLF Technical Group Action Plan, 2011-2016

*Note: the final scope of the plan will be determined by the task force members*

### **Task Force for Action Plan1: Closing the Technology Gaps**

The Carbon Sequestration Leadership Forum (CSLF) has had a significant focus on encouraging and facilitating research, development, demonstration and deployment of effective, low-cost CO<sub>2</sub> capture and storage (CCS) technologies. If CCS is going to be applied broadly, at large scale, it is essential that the technology is refined to deliver safe, low-cost, efficient storage in a wide range of situations. As a contribution to the global effort on CCS the CSLF will focus attention on the gaps and opportunities associated with the technology, with a view to speeding up the technology delivery at a global level and getting more focus on the critical gaps and opportunities that can make a significant difference by 2025.

As the global effort on CCS moves increasingly to large scale demonstration, there is an increasing amount of effort going into research and development and an increased number of governments and companies tackling pilots and demonstrations. This is complimented by a growing offering of technology and technology support for CCS. On the capture side the traditional amine capture technology is being installed or planned on large projects. A number of Original Equipment Manufacturers (OEMs) have developed their own technologies and are offering either enhancements on the amine technologies or new technologies, particularly insolvents.

On the transport and storage side, global experience and knowledge is growing. The decades of experience in enhanced oil recovery, combined with many project-years operating experience in carbon storage projects such as Sleipner, Snøhvit, and In Salah as well as the exploration and planning work that has been undertaken for projects such as Gorgon, Boundary Dam, ROAD, Decatur, etc. represent a substantial body of global knowledge. Research institutions around the world and their associated demonstration projects have also built a strong basis in the science and subsurface engineering.

It is clear however that, despite the efforts and developments in capture, storage and monitoring and verification to date, driving down the costs is still an overriding imperative. This can only be achieved by developing and refining more efficient technology and integrating the learning that comes from deployment in pilot and demonstration facilities around the world.

### ***Mandate***

At the CSLF meetings in Beijing, China (September 19-23, 2011) the CSLF Technical Group agreed that the Secretariat should circulate, by the end of the first week of October, a listing of the twelve actions of its five years Action Plan to Technical Group delegates with the request that that each CSLF Member provide a ranking by priority of importance. Delegates were asked to respond within three weeks and the results were then compiled by the Secretariat. Results from this survey were used to decide which actions to undertake immediately and which ones to defer. The Secretariat was also asked to solicit ideas for additional actions from the delegates.

Specifically, the prioritized actions of the five-year plan include Action Plan 1: Technology gaps. The formation of a task force to implement Action Plan 1 was proposed.

### ***Membership***

Australia has agreed to lead or co-lead the task force. Membership of this task force is open to CSLF member countries and interested parties. *[Note: those interested in participating on the task force as a member or co-lead should contact the CSLF Secretariat or Dr. Richard Aldous of CO2CRC, Australia ([raldous@co2crc.com.au](mailto:raldous@co2crc.com.au))]*

### ***Outcome***

The outcome of the Technology Gaps Task Force will be the identification and review of new updated critical technology gaps and opportunities for capture transport, storage and environmental monitoring and verification. The identification of the significant gaps and opportunities should be of interest to governments, companies and researchers and technology developers around the world. It may be of particular value to those organizations looking to foster international collaboration and optimization of the technology effort.

### ***Action and Scope***

To obtain this outcome, the task force will identify and review the spectrum of technologies and emergent technologies, looking for any critical gaps but also identifying the opportunities to substantially reduce costs and get better operational and environmental outcomes.

Suggested approach:

1. Identify 2-3 participants interested in each of
  - a. Capture technologies
  - b. Transport technologies
  - c. Storage( sub surface issues and MMV) technologies
  - d. Environment monitoring, including submarine monitoring technologies
2. Define an agreed process to assemble information using an agreed standardized template on each major aspect or sub element for each of the above technology areas, for example:
  - a. Technology dimension: e.g., Adsorbent technologies or new solvents ,etc.
  - b. Current status of technology: Advanced technology developments only (e.g., already at pilot scale as a minimum).
  - c. Who are the main players in this area.
  - d. Technology shortfalls gaps risks and opportunities associated with the technology
  - e. Potential for a major breakthrough deliverable to market by 2025, (high, medium, low).
  - f. Potential for a deliverable cost reduction in the next 10 years stated as percentage improvement against of a benchmark CCUS system.
  - g. Estimated cost to deliver improvement or cover gap.
  - h. Collaboration potential.
3. Synthesize data from the above into a report to be delivered by June each alternate year starting in 2013.
4. The reports will set out high level gaps and opportunities, with recommendations on how the global technology development pathway could be sped up or enhanced to further drive down costs and get better outcomes.



## **TECHNICAL GROUP**

### **Status of Proposed CSLF Liaison with ISO**

Barbara N. McKee  
Tel: 1 301 903 3820  
Fax: 1 301 903 1591  
[CSLFSecretariat@hq.doe.gov](mailto:CSLFSecretariat@hq.doe.gov)



## CSLF IS GOING GREEN\*

### STATUS OF PROPOSED CSLF LIAISON WITH ISO

*Note by the Secretariat*

#### Background

The International Organization for Standardization (ISO) has a technical committee on Carbon Dioxide Capture, Transportation, and Geological Storage (ISO/TC 265). The ISO encourages liaisons between its technical committees and outside organizations and, in that regard, the ISO/TC 265 has recently received requests for liaison status from the Global CCS Institute, the International Energy Agency (IEA), the IEA Greenhouse Gas R&D Programme (IEA GHG), and the European Industrial Gases Association (EIGA). The CSLF Technical Group, via the new Task Force on Monitoring Geologic Storage for Commercial Projects, has recommended that the CSLF also request liaison status, as this would be beneficial to several of the Technical Group's task forces. To that end, in August 2012 the CSLF Policy Group Chair sent a letter to the ISO/TC 265 Secretariat requesting liaison status. This document provides a copy of the letter sent from Policy Group Chair Charles McConnell to ISO/TC 265 Secretariat Chair Jeff Walker, the response received from Mr. Walker, and a reply sent to Mr. Walker by Secretariat Director Barbara McKee.

#### Action Requested

The Technical Group is requested to review the document.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.



August 30, 2012

Mr. Jeff Walker  
ISO/TC 265 Secretariat  
Canadian Standards Association  
5060 Spectrum Way, Suite 100  
Mississauga, Ontario L4W 5N6  
Canada

**RE: Request for Liaison Status with ISO/TC 265**

Dear Mr. Walker:

On behalf of the Carbon Sequestration Leadership Forum (CSLF), I am writing to request a liaison status with International Organization for Standardization's (ISO) Technical Committee 265 on Carbon Dioxide Capture, Transportation, and Geological Storage (ISO/TC 265). The CSLF is a ministerial-level international multilateral initiative focused on the development and deployment of cost-effective carbon capture, transport, utilization and long-term storage technologies. Established in 2003, the CSLF currently has 24 country members and the European Commission.

A short document that describes the CSLF is attached. If you have any questions or need further information about the CSLF, please contact Ms. Barbara McKee, Director of the CSLF Secretariat at 1-301-903-3820, or at [cslfsecretariat@hq.doe.gov](mailto:cslfsecretariat@hq.doe.gov). We look forward to your response to our request.

Sincerely,

Charles D. McConnell  
Chairman, CSLF Policy Group, and  
Assistant Secretary  
Office of Fossil Energy  
U.S. Department of Energy

Attachment



## **CARBON SEQUESTRATION LEADERSHIP FORUM BACKGROUND**

The Carbon Sequestration Leadership Forum (CSLF) was established in 2003 as a multilateral governmental ministerial-level international climate change initiative that is focused on the development of improved cost-effective technologies for the separation and capture of carbon dioxide for its transport, utilization and long-term safe storage in geological media. The purpose of the CSLF is to make these technologies broadly available internationally, facilitate knowledge sharing and identify and address wider issues relating to carbon capture, utilization and storage (CCUS).

The CSLF consists of 25 members: Australia, Brazil, Canada, China, Colombia, Denmark, the European Commission, France, Germany, Greece, India, Italy, Japan, Mexico, the Netherlands, New Zealand, Norway, Poland, Russia, Saudi Arabia, South Africa, South Korea, the United Arab Emirates, the United Kingdom and the United States. Membership is open to national governmental entities that are a significant producer or user of fossil fuels and that have the potential for carbon capture, utilization, and/or storage.

CSLF achievements include: convening six workshops on capacity building in emerging economy countries where information on CCUS technologies was presented by world-class experts in these technologies; recognition of more than 30 collaborative projects as a means to demonstrate the breadth and richness of ongoing CCUS activities throughout the world; acceleration of the creation of legal and regulatory frameworks for CCUS by developing guidelines for such frameworks; identification of key CCUS R&D needs and technology gaps; completion of a CCUS Technology Roadmap for all major players to work together for development and deployment of CCUS technologies; development of a stakeholder involvement strategy; and development of proposed standards for estimating geologic carbon dioxide storage capacities. More information about CSLF's activities is available on at the CSLF website: [www.cslforum.org](http://www.cslforum.org).

At the fourth CSLF Ministerial Meeting, held in Beijing in September 2011, CSLF Ministers welcomed additional international collaborations on CCUS. The CSLF's Technical Group is continuing its work concerning standards and guidelines in the area of geologic storage of CO<sub>2</sub>, with currently several task forces focusing on various aspects of CO<sub>2</sub> storage. Thus, we believe that formal status and liaison with the ISO in regard to ISO TC 265 would, therefore, be beneficial to both organizations.

## CSLF Secretariat

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**From:** Jeff Walker [jeff.walker@csagroup.org]  
**Sent:** Wednesday, September 12, 2012 2:23 PM  
**To:** CSLF Secretariat  
**Subject:** CSLF liaison with ISO CCS committee

Dear Ms. McKee,

I received a letter from Charles McConnell requesting liaison status with the ISO TC265 on CCS. Thank you for your interest.

There is a process to becoming a liaison to TC265, and it starts with information that you can provide. The letter from Charles covers some of the information. The first step is to identify what kind of liaison CSLF wishes to be. There are three categories.

**Category A:** Organizations that make an effective contribution to the work of the technical committee for questions dealt with by this technical committee. Such organizations are given access to all relevant documentation and are invited to meetings. They may nominate experts to participate in a WG

**Category B:** Organizations that have indicated a wish to be kept informed of the work of the technical committee. Such organizations are given access to reports on the work of a technical committee or subcommittee.

**Category D:** Organizations that make a technical contribution to and participate actively in the work of a working group

The next step is to obtain approval from ISO Central Secretariat that you qualify for liaison status. Can you send me a copy of CSLF's statutes or bylaws and your confirmation that CSLF,

- is not-for-profit;
- is a legal entity somewhere;
- is open to members worldwide or over a broad region; (covered by Charles' letter)
- has activities and membership demonstrating that the organization has the competence to contribute to the development of International Standards or the authority to promote their implementation. (covered by Charles' letter)

Once you have passed that hurdle, TC265 will need to approve the liaison. This is done through a committee ballot. With the ballot, I can submit on CSLF's behalf, a short description detailing CSLF's expertise/involvement in CCS and what value their involvement would bring to the committee. (I would say this is covered by Charles' letter)  
If you have any further questions, don't hesitate to contact me.

Regards,  
Jeff Walker

**Jeff Walker, P.Eng, M.Eng, MBA**  
ISO TC265 Secretary

T 416 747 2720  
F 416 401 6728  
[jeff.walker@csagroup.org](mailto:jeff.walker@csagroup.org)

**From:** Barbara McKee  
**Sent:** Wednesday, September 26, 2012  
**To:** Jeff Walker  
**Cc:** CSLF Secretariat  
**Subject:** RE: CSLF liaison with ISO CCS committee  
**Attachments:** CSLF Charter 2011.pdf;  
CSLF Terms of Reference and Procedures.pdf;  
CSLF Technology Roadmap 2011.pdf

Dear Mr. Walker:

Thank you for your email and I can confirm that the CSLF is a not-for-profit organization.

The CSLF wishes to become a Category A Organization with regards to liaison with the ISO's TC265 CCS Committee. Attached, for your information, are copies of the CSLF Charter and the Terms of Reference. The Charter has been signed by Energy Ministers of the CSLF Member Countries (including the European Commission). One of the many activities of the CSLF has been Review and Identification of Standards for CO<sub>2</sub> Storage Capacity Estimation, for which reports were issued in 2005, 2007, and 2008. These reports are online at the CSLF website: <http://csforum.org/publications/>. The CSLF has also produced a Technology Roadmap, a copy of which is attached.

We look forward to hearing from you.

Very truly yours,

Barbara N. McKee  
Director,  
CSLF Secretariat



## **TECHNICAL GROUP**

### **Draft Concept Paper for the Fifth CSLF Ministerial Conference**

#### **Decision Document**

Barbara N. McKee  
Tel: 1 301 903 3820  
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[CSLFSecretariat@hq.doe.gov](mailto:CSLFSecretariat@hq.doe.gov)



## CSLF IS GOING GREEN\*

### DRAFT CONCEPT PAPER FOR THE FIFTH CSLF MINISTERIAL CONFERENCE

*Note by the Secretariat*

#### Background

The first four CSLF Ministerial Meetings were held in Tysons Corner, Virginia, USA in June 2003, in Melbourne, Australia in September 2004, in London, United Kingdom in October 2009, and in Beijing, China in September 2011. A fifth Ministerial Meeting is now proposed, as required every two years under Section 3.2(b) of the Terms of Reference and Procedures.

In their September 22, 2011 Communiqué, following deliberations at the Beijing CSLF Ministerial Meeting, CSLF member country Ministers and Heads of Delegation affirmed that CO<sub>2</sub> Capture, Utilization and Storage (CCUS) is an indispensable element of any effective response to climate change and urged the world to increase the number of large demonstrations to enable the deployment of CCUS commercially by the end of this decade. The Ministers also applauded the decision at last year's United Nations Framework Convention on Climate Change (COP 16) to recognize CCUS as a measure in the Clean Development Mechanism (CDM). The Ministerial Communiqué further observed that the Ministers:

*“...Met today to discuss and address the key challenges facing CCUS and identify activities necessary to support further research, development, demonstration and deployment. While it is clear that significant progress is being made on CCUS, challenges remain, but these are challenges that can—and will—be overcome... We support strategies for the CSLF to resolve barriers for successful implementation of CCUS projects at a time of significant global economic challenge. We will work with the private sector to develop and implement methods to finance projects, including those in developing countries. We will work to develop legal and regulatory mechanisms to assure safety and appropriately allocate liabilities between the public and private sectors appropriate to our national circumstances. We will strengthen cooperation on both technology and policy in order to reduce the financial costs, to lower the energy penalty and to allay public concerns associated with the deployment of CCUS technologies... We task the CSLF to undertake CCUS development initiatives...”*

The Ministers also indicated that they welcomed additional international collaborations on CCUS through the International Energy Agency (IEA) the Global CCS Institute, and the Clean Energy Ministerial (CEM).

Since the last Ministerial Meeting, the CSLF has undertaken many activities in response to Ministerial guidance. A Ministerial Meeting at this time would formally take note of what the CSLF has achieved and recommit to its objectives at the ministerial level, would provide

further guidance, and would greatly strengthen global momentum in moving forward with CCS and CCUS.

After reviewing the deliberations and conclusions of the last Ministerial meeting and considering the current global situation with regard to climate related actions and CCS/CCUS, the CSLF Secretariat has prepared a draft concept paper for the fifth CSLF Ministerial Meeting. This draft concept paper is intended as a starting point for discussions.

### Action Requested

The Policy and Technical Groups are requested to consider the Draft Concept Paper for the fifth Ministerial Conference prepared by the Secretariat and to consider the proposed CSLF Ministerial Meeting.

As stated in the Draft Concept Paper, the strongly suggested theme for this Conference is “The Business Case for CCUS: Carbon Utilization to Meet Energy Sustainability, for Economic Development and to Fight Poverty.” CCUS enables the deployment of CO<sub>2</sub> capture technology even in the absence of forcing carbon legislation or regulation by creating a market driver for the CO<sub>2</sub> as a commodity, especially in CO<sub>2</sub>-EOR applications. EOR is the business driver for catalyzing CCUS, while providing economic drivers for commercial projects. It can improve a country’s balance of trade, increase domestic economic activity, create jobs and promote energy security. International collaboration can assist developing countries in pooling their resources, forming project alliances and pursuing commercial scale CCUS projects.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.

Draft as of 14 September

## Concept Paper

### FIFTH CSLF MINISTERIAL CONFERENCE - 2013

#### 0. Background

This Concept Paper outlines issues, which might be debated, and presents options for the fifth CSLF Ministerial Conference, which is proposed to be held during 2013. The options aim at ensuring visibility to the event, the main issues and practical outcomes while promoting wide and qualified attendance. The last Ministerial Conference identified new opportunities for CCS through CCUS. The fifth Ministerial Conference can build on the conclusions of the fourth Ministerial Conference and the CSLF activities to date; which can continue to grow momentum for CCUS. It can also introduce new momentum and impulse into the CSLF process and the emerging international partnerships.

#### 1. Scope of the Ministerial Conference and Expected Outcome

**a) General Theme:** A general theme is recommended to provide the Conference with mission, focus and guidance. The suggested theme is *“The Business Case for CCUS: Carbon Utilization and Storage to Meet Energy Sustainability, for Economic Development and to Fight Poverty.”* CCUS enables the deployment of CO<sub>2</sub> capture technologies even in the absence of enabling carbon legislation or regulation by creating a market driver for the CO<sub>2</sub> as a commodity, especially in CO<sub>2</sub>-enhanced oil recovery (CO<sub>2</sub>-EOR) applications. CO<sub>2</sub>-EOR is a business driver for catalyzing CCUS, while providing economic drivers for commercial projects. It can improve a country’s balance of trade, increase domestic economic activity, create jobs and promote energy security and environmental sustainability. In addition, CO<sub>2</sub>-enhanced coalbed methane (ECBM) recovery and CO<sub>2</sub>-enhanced gas recovery (EGR) are positioned to further expand market opportunities for CCUS. International collaboration can assist developing countries in pooling their resources, forming project alliances and pursuing commercial scale CCUS projects.

**b) Framework:** According to the CSLF Charter, the purpose of the CSLF is *“to accelerate the research, development and commercial deployment of improved, cost-effective technologies for the separation and capture of CO<sub>2</sub> 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, demonstration and commercial deployment of such technology.”*

The fifth Ministerial Conference will be held in a highly dynamic policy framework. Global policy, strategy, legislation and legal frameworks on climate change remain unresolved in many

countries. While the decision at last year's United Nations Framework Convention on Climate Change (COP 16) to recognize CCUS as a measure in the Clean Development Mechanism (CDM) showed progress, it can be assumed that differences will remain among the parties on how to respond to the global climate challenge. Carbon Capture, Utilization and Storage (CCUS) remain a win-win option in this circumstance.

**c) Energy and Environment Context:** Since the time of the 1997 Kyoto Protocol, there has been only limited global progress in curbing CO<sub>2</sub> emissions. The current global mechanisms have not yet been successful in achieving the broad commercial deployment of CCS. The global recession has partly contributed to the limited progress, as has the high cost of low carbon emission technologies. CCUS offers the potential for being able to make major reductions in carbon emissions, but the current cost of CO<sub>2</sub> capture is high and there is major uncertainty in some countries as to how CCS will be regulated. The purpose of this Ministerial is to identify the best path forward for CCUS in the current political, legislative, regulatory and economic climate. The ideal pathway would be one that is economically viable and makes business sense, even in the absence of legislative and regulatory drivers for CCS.

Ranges of experts and analyses have generally concluded that CCS may be essential to meeting global climate goals. Some global leaders have drawn the same conclusion. Former UK Prime Minister Tony Blair stated that *“developing carbon capture and storage technology is not optional, it is literally of the essence.”*<sup>1</sup> Norway's Prime Minister Stoltenberg remarked, *“With nine billion people expected on the planet in 2050, there is no way we can choose between increased energy production and reduced CO<sub>2</sub> – we have to achieve both. Without CCS, we cannot do it.”*<sup>2</sup> Steven Chu, U.S. Secretary of Energy, in a recent article in Nature magazine wrote, *“If the world is to continue to produce electricity from fossil fuels, the carbon emissions from major point sources will have to be significantly reduced in the coming decades. Carbon capture and storage from coal and natural gas power plants and other major emitters, such as cement and steel plants, will be necessary. Also, the International Energy Agency concluded that a climate strategy with CCS would have approximately half the marginal cost in 2050 of a program lacking CCS technology, and (under IEA's assumptions) global cost savings attributable to CCS would total \$1.3 trillion per year in 2050.”*<sup>3</sup>

The world will be dependent on fossil fuels for the foreseeable future and policy makers throughout the world are increasingly aware of this fact. Developing economies will be the major source of energy demand growth, but all countries need energy for economic and social progress and all countries aspire for supply security and a sustainable fuel mix. CCUS will enable the world to use fossil fuels in a more sustainable way, thus easing shared concerns about development, energy security and social progress. However, CCUS must be commercially viable.

CCS market deployment is confronted with the barriers of high cost, project risks, lack of

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<sup>1</sup> [Breaking the Climate Deadlock, A Global Deal for Our Low-Carbon Future \(speech\)](#), T. Blair, The Climate Group, 2008.

<sup>2</sup> [Whatever happened to carbon capture in the fight against climate change?](http://www.guardian.co.uk/environment/2012/may/09/carbon-capture-storage-climate-change), D. Carrington, *The Guardian*, May 9, 2012, <http://www.guardian.co.uk/environment/2012/may/09/carbon-capture-storage-climate-change>.

<sup>3</sup> [Energy Technology Perspectives - 2008](#), Table 2.5, International Energy Agency, 2008

economic incentives and uncertain legal and regulatory frameworks for carbon dioxide transport, storage and the associated liabilities. CCUS can bridge these barriers, but barriers differ among countries and each country must choose the set of measures that best meets its national objectives and circumstances while at the same time supporting the development of regional and international cooperation and cross-border movement of CO<sub>2</sub>.

**d) Policy Imperative:** The key policy imperative is to reach agreement on a strategy for the broad commercial deployment of CCUS in the current global climate and to accelerate its deployment. Even though the precise nature of the agreement that will emerge is not known, it is expected that substantial cuts in carbon dioxide emissions are likely to be required. It is therefore necessary to ensure that CCUS is market deployable when the global outcomes have been agreed upon.

There is also a need to reaffirm agreement on and a willingness to promote CO<sub>2</sub>-EOR as the key component of CO<sub>2</sub> utilization in an effective CCUS strategy. Using CO<sub>2</sub> for EOR is a promising strategy for the commercial deployment of CCS in the current climate. CO<sub>2</sub>-EOR provides for the use of captured CO<sub>2</sub> from power and other industrial plants to facilitate additional production of crude oil via CO<sub>2</sub>-EOR, and the accompanying revenue from its sale. Governments would also benefit from the increased oil production through increased tax revenues and the availability of such oil from either domestic resources or from other secure sources – all of which would strengthen national and global economies. However, such projects also convey significant technical, economic and environmental risks to their sponsors. An incentives program and legal/regulatory clarity is likely to be required to encourage project sponsors to take on the associated risks, as well as a commitment to invest in R, D, &D projects to bring down the cost of CO<sub>2</sub> capture technology. It is also worth noting that CO<sub>2</sub> storage in depleted oil and gas fields and deep saline formations will be required over time to realize the full CCS mitigation potential and demonstration projects must start now.

**e) Government Action:** Governments need to know when CCUS is commercially available and market deployable. Accordingly, Governments will consider what measures they need to take to ensure or accelerate that availability and deploy ability, including pursuing the actions identified as outcomes from the proposed Ministerial Meeting (see subsection h “**Expected Outcomes**” below).

**f) Key Issues:** Key issues for CCUS market deployment are:

- ❖ **Issue A:** Willingness of countries to invest in the development and demonstration of additional large-scale CCUS projects and to assure the success of ongoing projects. Such investment must be made to bring down the costs of CCS, as well as to improve its maturity. CCS technology immaturity is not frequently highlighted but it is a key impediment. Energy producers continue to be concerned that adding CCS at current technology costs would raise the cost of energy, whether it is electricity or liquid fuel, to the point that they could not pass costs through to the consumer and therefore could not pursue CCS.
- ❖ **Issue B:** Willingness of countries to commit to and invest in a winning CCUS deployment strategy. The issues impeding the commercial deployment of CCS have not changed over the last 15 years, which include high CO<sub>2</sub> capture cost, large scale application of technology, technology immaturity, risk allocation, liability, financing, public acceptance, absence of

binding legislation, regulatory uncertainty and more recently the global economic recession. There is a critical need to adopt a CCUS strategy that can overcome these issues by making a business case for the broad commercial deployment of CCUS. Given the current global situation, the most promising strategy for some countries would be to “kick start” a global CO<sub>2</sub>-EOR business using captured anthropogenic CO<sub>2</sub>.

- ❖ **Issue C:** Willingness of countries to make sufficient and especially timely investment in advancing CO<sub>2</sub> capture and related technology performance and cost. Timely investment is needed in component research and development to reduce parasitic energy consumption (including solvent regeneration, compression, gas separation, and solids management), which leads to components at scale that can be retrofitted on existing installations and integrated with existing demonstrations for the purpose of commercialization.
- ❖ **Issue D:** Willingness of countries to pursue environmental, legislative and regulatory strategies that would eliminate any obstacles and would incentivise the use of captured anthropogenic CO<sub>2</sub> for EOR applications.
- ❖ **Issue E:** Willingness of countries to pursue environmental, legislative and regulatory strategies that would eliminate any obstacles and would incentivise the deployment of CCS systems.
- ❖ **Issue F:** Willingness of countries to aggressively incentivize CO<sub>2</sub> capture to overcome the absence of legislative/regulatory requirements to curb CO<sub>2</sub> emissions from gas power plants. Climate strategies cannot be achieved without deploying CO<sub>2</sub> capture on gas plants as well as all other fossil energy sources.
- ❖ **Issue G:** Willingness of developing countries to invest in and enable the deployment of CCUS in their respective countries.
- ❖ **Generic Issues:** The key generic issues, previously identified by the CSLF, specific to CCS and relevant to CCUS as well include:
  - Need to ensure a level playing field for CCUS technologies with other low carbon or zero carbon technologies.
  - Lowering the cost of capture to commercially and economically practicable levels particularly in electricity generation.
  - Developing public confidence in the integrity of the entire CCUS process.
  - Need to ensure a major consultation and outreach process on CCUS to communicate the need for and the benefits of CCUS.
  - Need to develop, where they do not already exist, appropriate legal/regulatory/fiscal frameworks to address intergenerational management of CCUS systems – the liability issue and who carries liability.
  - Need to make sure that the ongoing work on legal/regulatory/fiscal measures does not constrain pilot, demonstration and commercial projects from being implemented.
  - Because of differing national circumstances, need to develop legal/regulatory/fiscal measures that are largely locally based for managing the use of CCUS technology.
  - Need to maintain a global research effort and public/private partnership.

- The IPCC work could be a policy driver – especially in terms of the technical issues and the creation of community confidence in CCUS.

**g) Priority of Issues:** The issue priorities are in the same sequence as listed in the Issues Section (A to G). This prioritization is consistent with accelerating CCUS through CO<sub>2</sub>-EOR. Countries that can and would wish to utilize tax and other incentives to accelerate CO<sub>2</sub> storage by making captured anthropogenic CO<sub>2</sub> economically attractive for CO<sub>2</sub>-EOR applications are likely to agree with this prioritization.

Countries or constituencies that are unable or unwilling to pursue a CCUS/CO<sub>2</sub>-EOR strategy, but desire to assure early CCS deployment would have to assign an even higher priority to making a large direct investment in multiple large-scale integrated CCS projects to bring down the cost of CCS, increase technology maturity, gain public acceptance and would also have to create a favorable economic, legislative and regulatory environment for their deployment. In this context, the prioritization by such countries would lower the issues which focus on CCS/CO<sub>2</sub>-EOR strategies toward the bottom of the issues list, but the prioritization of the remaining issues would remain as listed in the Issues Section.

**h) Expected Outcomes:** Important desired outcomes from the fifth Ministerial Conference include the following:

- ❖ Reaffirmation that governments will work to create the business case for CCUS.
- ❖ Reaffirmation of the importance of CCUS to a global climate strategy, energy security economic development and fighting poverty. Endorse international collaboration to pursue at least one commercial scale CCUS project in developing countries.
- ❖ Reaffirmation of the need for countries to make the necessary and especially timely investment in research and development on carbon capture technology to bring down its cost.
- ❖ Reaffirmation that all fossil fuels will continue to be used and that CCUS is needed to make them sustainable.
- ❖ Reaching agreement that both oil consumers and producers benefit from EOR.
- ❖ Reaching agreement and issuing statement that CCUS and central power plants are needed to reduce poverty.
- ❖ Reaching agreement on and endorsement of a CCUS strategy that will accelerate the early deployment of CCUS in the current global political, legislative, regulatory and economic environment. This would necessarily have to be a strategy that can succeed even in the absence of binding climate legislation and regulation. For some countries, the winning strategy would be utilizing captured anthropogenic CO<sub>2</sub> and using it for CO<sub>2</sub>-EOR and, potentially, for enhanced gas or coalbed methane production.
- ❖ Reaching agreement on and endorsement of a set of incentives that must be implemented by Governments to achieve the agreed upon strategy, including direct investment and tax credits to reduce the cost of the captured CO<sub>2</sub> into the range required to make CO<sub>2</sub>-EOR

commercially feasible. The additional oil thereby produced should yield revenue streams (such as additional tax revenues) that should offset the cost of the tax credits.

- ❖ Reaching Ministerial commitment to pursue the necessary financial incentives in their respective countries to enable the agreed upon strategy.
- ❖ Reaching Ministerial agreement to promote CO<sub>2</sub>-EOR as the key component of CO<sub>2</sub> utilization for an effective CCUS strategy.
- ❖ Reaching Ministerial agreement to endorse environmental legislative and regulatory strategies that would encourage the use of captured, anthropogenic CO<sub>2</sub> for CO<sub>2</sub>-EOR.
- ❖ Identifying follow-on action for the next Ministerial Meeting to assure a continuity of effort and maximizing the pursuit of opportunities and growing the momentum for CCUS deployment.

## 2. Draft Agenda for the Ministerial Meeting

- a) **Calendar:** The Ministerial Meeting and the related events would develop over three days:
  - i) First Day: Policy and Technical Group Meetings
  - ii) Second Day: Parallel Events: Stakeholder's Dialogue and Outreach Forum. Ministers may wish to be present and possibly participate as speakers at selected sessions.
  - iii) Third Day: Ministerial Forum organized along three main Sessions and a Ministerial Statement.
  - iv) A CCS/CCUS projects exhibition will be organized and maintained for the full duration of the Ministerial Meeting and related events.
- b) **Policy and Technical Group:** Meetings will have their standard agenda and should provide the opportunity to fine tune the Ministerial Statement.
- c) **Stakeholders:** Dialogue would focus on the different but complementary roles of governments and various Stakeholders, social consensus and transparency of information. A joint CCS data collection and information exchange initiative might be advocated to facilitate public understanding, acceptance and support. The Stakeholders' Register might also receive a boost.
- d) **Outreach Forum:** The Forum should gather interest and involvement from non-CSLF participant entities (countries, international organizations and non-industry stakeholders).

## 3. Choice of Chairs, Discussants, and Background Papers

- a) The entire Ministerial Forum will have a Chair and two Co-chairs. Co-chairs will be selected from countries chairing or co-chairing the CSLF Policy and Technical Groups. The Ministerial Forum will have three sessions. Background papers will be prepared addressing the key issues.

b) Tentative titles for the Ministerial Sessions:

Session 1: The Strategic Role of Fossil Fuels and Carbon Capture, Utilization and Storage to Secure a Sustainable Energy Future

Session 2: The Business Case for CCUS and for Advancing Carbon Sequestration

- Presentation by the Global CCS Institute on the opportunities for 4-5 additional large-scale CCUS projects in developed countries, to include both EOR and CCS.
- Presentation by the Asian Development Bank on the opportunities for at least one large-scale CCUS project in developing countries.

Session 3: The CSLF Role for Accelerating CCUS Deployment and to Respond to the Global Challenges, including enabling, facilitating financing and incentivizing large-scale CCUS Projects

- c) The Minister from the hosting country will chair Session 1 and Present the Closing Statement. Ministers from the co-hosting countries will chair Sessions 2 and 3, respectively. A panel would be included in each session and would help to stimulate the discussion. The Panel would include the Chair, a Discussant (or Moderator), and two Ministers or Heads of International Organizations. General discussions will follow. The Chair will make a short summary at the end.
- d) Two to three background papers or discussion documents will be prepared. The papers will set the framework and suggest points for discussion. The papers could be prepared by international organizations such as the International Energy Agency, United Nations Environment Program, World Bank, and World Energy Council. Aspects covered must be central to the topics of the three conference sessions and could include the business case for CCUS (which could include both EOR and CCS), the global energy scene, the long-term energy policy views, the obstacles to investment and opportunities -- including identifying tools and actions to implement and enhance international cooperation.
- e) The specific subjects of the papers could include the following:

- A report on what makes some projects succeed and others fail.
- A paper suggesting creative new ways to finance demonstration projects, perhaps by countries collaborating.
- A paper discussing a possible initiative that could be pursued by developing countries to do a CCUS project in a CSLF developing country that would be of adequate scale technically and of interest to technology vendors, but small enough to be affordable.
- A paper on using CSLF project recognition as a vehicle for further collaboration/information sharing.
- A paper providing information, such as the CURC Roadmap, to convey what needs to be done. The latter paper must:

- Clearly describe the sustained effort, phases, and time needed to make CCUS commercial.
- Discuss environmental policies that would be support or impede the development of critically needed technology.
- Support the need to do projects at scale.
- Discuss the elements of an effective deployment strategy.

#### **4. Stakeholders' Dialogue and Outreach Forum**

- a) The Stakeholders' Dialogue will examine how to promote public/private partnerships (i.e. cooperation between governments and industry) and social acceptance. The Dialogue could be a full day event and could be organized into Sessions. Non-government organizations will have a key role. Ministers may wish to attend and intervene. Each Session will be introduced by a keynote speech. Stakeholders' will be invited by the host country and by the countries participating in the CSLF.
- b) The Outreach Forum will involve countries and international organizations, which are not formal participants in the CSLF.
- c) Stakeholders' discussion as well as Outreach Forum debate will be reported at the Ministerial Forum.

#### **5. Participation in the Ministerial Meeting**

- a) Who should participate: Ministers and their staff, Heads of international organizations, observers, and technical staff.
- b) Issues papers should be circulated in advance. Ministers should know they have a mission.
- c) Identification of global personalities as speakers. Some possibilities include Jeffrey Sachs, IEA Director, Bill Clinton, Head of WEC, Bill Gates, Microsoft and, from India, the heads of Reliance and TATA

#### **6. Organizing Stakeholders while Providing Them with a Role**

The choice of themes is important e.g. opportunities for socially responsible investors, challenges and opportunities for sectors and firms, etc.

#### **7. How to Communicate the Results of the Ministerial Meeting**

A communications strategy is necessary for interacting with the press and the media. Each day should make the news by planning a special news release.

- a) Should take advantage of the EOR industry in Houston and Texas to highlight what can be done for CCUS.
- b) Should emphasize utilization, which should include more than just EOR—chemicals, for example.

- c) Should focus attention on all aspects of CCUS including capture, storage, EOR, and economic and energy security benefits.
- d) Should emphasize the importance of CCS.
- e) All messages need to be carefully crafted and negotiated for broad acceptance.
  - Work with IEA to help support the right messages.
  - Messages need to be consistent with energy ministers, not environmental ministers.

#### **8. Proposals and Guidance Emerging from Recent International Events.**

Relevant international conferences and other events must be reviewed in terms of what role they may play in shaping the outlook for CCS and their results should be assessed for what impact they may have on the Ministerial.

#### **9. Organizing a Technology Expo**

Include a Technology Expo as part of the Ministerial

- a) Special tour and site visits for ministers and media
- b) Have in an area where people congregate (e.g., receptions area)
- c) Highlight US industry, but open to companies from all CSLF members
- d) Highlight both utilization/EOR and CCS (especially benefits and successes)

# Carbon Sequestration Leadership Forum

CSLF-T-2012-19  
14 September 2012

[www.cslforum.org](http://www.cslforum.org)



## **TECHNICAL GROUP**

### **Election of CSLF Officials**

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# Carbon Sequestration Leadership Forum

CSLF-T-2012-19  
14 September 2012

[www.cslforum.org](http://www.cslforum.org)



## CSLF IS GOING GREEN\*

### ELECTION OF CSLF OFFICIALS

*Note by the Secretariat*

#### Background

As stated in Section 3.3 (a) of the CSLF Terms of Reference and Procedures, CSLF Chairs and Vice Chairs will be elected every three years. The previous election of the Policy Group Chair, Technical Group Chair, and Technical Group Vice Chairs was at the London meeting in October 2009, so the next election has been scheduled for the October 2012 CSLF Annual Meeting in Perth, Australia.

#### Action Requested

The Policy Group is requested to hold an election to select a Chair whose term will run through October 2015. The Technical Group is requested to hold an election to select a Chair and Vice Chairs whose term will run through October 2015.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.

# **Election of Policy Group Chair, Technical Group Chair, and Technical Group Vice Chairs**

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

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

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

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

On 19 June 2012, the Secretariat sent an e-mail to CSLF Policy Group delegates, informing them of the upcoming election of the Policy Group Chair, the Technical Group Chair, and the Technical Group Vice Chairs, and that nominations must be received by the Secretariat no later than six weeks prior to the meeting (i.e., by 12 September 2012).

The following nominations were received by the Secretariat:

- Australia, Japan, Mexico, and Norway have nominated the United States for Policy Group Chair.
- Australia, China, Mexico, and the United States have nominated Norway for Technical Group Chair.
- Australia, China, Mexico, and the United States have nominated Canada for Technical Group Vice Chair.
- Australia, China, Mexico, and the United States have nominated South Africa for Technical Group Vice Chair.
- China, Mexico, and the United States have nominated Australia for Technical Group Vice Chair.



**POLICY GROUP  
TECHNICAL GROUP**

**Revised Draft  
Minutes of the Joint CSLF  
Policy and Technical Group Meeting**

**Beijing, China  
23 September 2011**



## CSLF IS GOING GREEN\*

MINUTES OF THE JOINT CSLF POLICY AND TECHNICAL GROUP MEETING  
BEIJING, CHINA  
23 SEPTEMBER 2011

*Note by the Secretariat*

### Background

The Policy and Technical Groups of the Carbon Sequestration Leadership Forum held a joint business meeting on 23 September 2011, in Beijing, China. Initial draft minutes of this meeting were compiled by the CSLF Secretariat and were circulated to the Policy Group and Technical Group delegates for comments. Comments received were incorporated into this revised draft. Presentations mentioned in these minutes are now online at the CSLF website.

### Action Requested

Policy Group delegates are requested to approve these revised draft minutes.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.



**DRAFT**  
**Minutes of the Joint Meeting of the**  
**Policy Group and Technical Group**  
**Beijing, China**  
**Friday, 23 September 2011**

## **LIST OF ATTENDEES**

### **Policy Group Delegates**

Chairman:	Charles McConnell (United States)
Australia:	Ann Boon, Margaret Sewell
Brazil:	Daniel Falcon Lins
Canada:	Marc D'Iorio, Milenka Mitrović
China:	Xin Li, Sizhen Peng
European Commission:	Wiktor Raldow
France:	Bernard Frois
Germany:	Hubert Höwener, Peer Hoth
Italy:	Liliana Panei
Japan:	Hirotsada Bessho, Shigenori Hata
Korea:	Byung Ki Park, Wonchang Yang
Mexico:	José Miguel González Santaló
Netherlands:	Paul van Slobbe
Norway:	Tone Skogen, Kristoffer Stabrun
Poland:	Janusz Michalski, Marek Wejtko
Saudi Arabia:	Abdulmuhsen Alsunaid, Abdullah AlSarhan
South Africa:	Elizabeth Marabwa, Muzi Mkhize
United Arab Emirates:	Keristofer Seryani
United Kingdom:	Jeremy Martin, James Godber
United States:	James Wood

### **Technical Group Delegates**

Australia:	Niki Jackson
Brazil:	Beatriz Espinosa, Viviana Coelho
Canada:	Stefan Bachu, Eddie Chui
China:	Ping Zhong
European Commission:	Jeroen Schuppers
Italy:	Giuseppe Girardi, Sergio Persoglia
France:	Didier Bonijoly
Japan:	Ryo Kubo
Korea:	Chang-Kuen Yi
Norway:	Trygve Riis (Chairman)
Saudi Arabia:	Khalid Abuleif
United States:	Joseph Giove, George Guthrie

## **CSLF Secretariat**

Barbara McKee, Jeffrey Price, John Panek, Richard Lynch, Adam Wong, Jeffrey Jarrett, Kathryn Paulsgrove

## **Observer Participants**

Dietrich M. Gross, Jupiter Oxygen (United States)  
John Lyman, Atlantic Council (United States)  
Andrew Paterson, CCS Alliance (United States)  
David Wendt, Jackson Hole Center for Global Affairs (United States)  
Tony Wood, Clinton Foundation

### **1. Opening Remarks**

Chairman McConnell welcomed the delegates to the last of several days of meetings. He said that the Ministerial meeting the previous day was terrific and that we would have a chance at this meeting to review the Ministerial, as well the meetings of the Policy Group and Technical Group.

The logistics of the planned site visit in the afternoon to the Huaneng Carbon Project were also discussed for the benefit for those planning to attend.

### **2. Adoption of Agenda**

The Agenda was adopted without change.

### **3. Review and Approval of Minutes from London Meeting**

The draft Minutes of the previous Joint Policy and Technical Group meeting held in Warsaw, Poland in October 2010, had been circulated for comment to the Policy Group prior to the meeting. The final draft, which incorporated comments received, had been posted on the CSLF website. The Minutes were approved without further change.

### **4. Review of Warsaw Action Items**

Barbara McKee, Director of the CSLF Secretariat, reviewed the status of the Action Items. She stated that all of the Action Items had been completed, except that:

- The Policy Group needed to consider a Task Force on Closing Policy-Related Gaps;
- Members were needed for the new Task Force on Risk and Liability; and
- The Secretariat and Communications and Public Outreach Task Force needed to identify best practices to most effectively move media communications forward.

The Technical Group noted that, in addition to a final 2010 Technology Roadmap called for in the minutes, a Technology Roadmap had also been completed in 2011.

### **5. Report from Policy Group**

Chairman McConnell of the Policy Group presented a report on the Policy Group meeting. That meeting consisted of task force reports, reports from collaborating organizations, CSLF planning and planning for the Ministerial.

Reports from Policy Group Task Forces included the following:

- Capacity Building Task Force and Governing Council. The CSLF Capacity Building Fund now totals US\$3 million and decisions have been made to fund projects in four countries. CSLF capacity building events are open to all Members. New projects are being sought and a funding strategy is to be developed for the next three years.
- Financing CCUS Task Force. The focus of this task force is on understanding commercial-scale financing needs with activities to date including workshops, expert dialogues and reports. A number of key findings have been reached including that CCUS can be cost-competitive with other low-carbon technologies.
- CCUS in the Academic Community. This task force has identified many CCUS-related courses worldwide and developed an extensive data base of courses on all aspects of CCUS. Further work will be to validate the data base and consider creating a network of professors to accelerate and improve CCUS education.
- Communications and Public Outreach. This task force has implemented a strategic plan to address barriers to public awareness and acceptance. Positive comments were received on the work, but much more needs to be done to follow up. The key issue is how to collaborate to improve communications on CCUS.

Reports were heard from four collaborating organizations: the International Energy Agency, the Global CCS Institute, the World Bank and the CCUS Action Group. Work of these organizations complements that of the CSLF. Several questions, however, need to be addressed:

- Is international collaboration adequate?
- Where can improvements be made?
- What synergies can be exploited?
- How is this reflected in outcomes or milestones in the CSLF Strategic Plan?

The Second Update of the CSLF Strategic was discussed and approved. This Update reflects the amended charter. It is goal-oriented with specific milestones. A fundamental question is raised as to how the CSLF, as a voluntary multilateral organization, can maintain clear progress toward common goals.

All six of the projects recommended for recognition by the Technical Group were approved. The total number of projects recognized since 2004 now total 36 and these projects cover all aspects of CCUS.

The Policy Group was also given an overview of plans for the September 21 Conference of Ministers as well as the four reports to the Ministers. Final edits were made to the Ministerial Communiqué.

### Comments

A number of comments were made by delegates on the presentations on the reports by the Policy Group Task Forces:

- Capacity Building Task Force and Governing Council. José Miguel González Santaló of Mexico stated that the effort on capacity building has been very intensive and that he expects there will soon be more proposals and that the organizational arrangements now work. Barbara McKee of the Secretariat responded that considerable effort had to go into developing the Terms of Reference and procedures for the Task Force and Governing Council and developing criteria for approval of projects to ensure and verify that they met real

needs of Members. Abudulmuhsen Alsunaid of Saudi Arabia reiterated that the process is now going forward and working. He also stated that part of the capacity building effort could also benefit developed countries, which also needed to build capacity. Governing Council Chair Tone Skogen of Norway noted that if no more money is forthcoming the plan may end and asked how the CSLF can leverage other means of funding. Jeremy Martin of the United Kingdom agreed with the previous comments and stated that he thought that it was too early to judge results. Li Xin of China thanked the donor countries and stated that he agreed with the previous comments. He also said that there were opportunities to learn from other projects and from other countries' proposals. Chairman McConnell noted that in the Ministerial there was agreement that capacity building was one of the most important issues.

- Communications and Public Outreach. Barbara McKee asked what would be needed to accelerate work in this area. Task Force Chair John Grasser of the United States restated the need for public affairs professionals to assist in CSLF efforts in this area and made a formal request for assistance from such professionals. Mr. Grasser also said that he has been in contact with the Global CCS Institute on this issue. He also reiterated that communications activities are expensive and that funding is not adequate in this area. Such funding as is available currently comes from the United States Department of Energy's internal budget, but it is considered well spent. Chairman McConnell stated that there was a need to leverage efforts in this area, that there will always be believers and non-believers and that it is important to segment audiences. Tone Skogen said that the CSLF should consider the experience of the European Zero Emissions Platform, which has a large communications task force and has produced information for the public. The need for simplified messages and outreach to science journalists was also mentioned.
- CCS in the Academic Community. Barbara McKee asked whether it was clear what the next steps were. Task Force Co-Chair Tim Dixon of the IEA GHG responded that the Task Force now has a work plan and needs to assign responsibilities at the next task force meeting.

## 6. Report from Technical Group

Technical Group Chairman Trygve Riis of Norway presented the report from the Technical Group. He said that since the last meeting in Warsaw, the following meetings have been held:

- Workshop and PIRT meeting in Al Khobar, Saudi Arabia, February 2011. This was a very successful workshop on storage and monitoring of CO<sub>2</sub> with excellent participation from storage projects.
- Technical Group meeting with Task Force meetings in Edmonton, Canada, May 2011. Two projects were nominated for CSLF recognition: Zero Emission Porto Tolle (ZEPT) and the Janschwalde Project. The Technical Group also visited the CSLF-recognized Quest project.

The Technical Group Executive Committee also has telephone meetings each month.

In Beijing, the Technical Group meeting consisted of a PIRT meeting, task force meeting and a meeting of the entire Technical Group. Four new projects were nominated for CSLF recognition:

- SaskPower CCS Project;
- CGS Europe Project;
- Rotterdam Opslag en Afvang Demonstratieproject (ROAD); and
- CO<sub>2</sub> Capture Project – Phase 3.

The 2011 Carbon Sequestration Leadership Forum Technology Roadmap (TRM) provides a pathway to the commercial deployment of integrated CO<sub>2</sub> capture, transport, and storage technologies. The current TRM update also reports on project and country activities. A major revision will be done every three year, with the next in 2013, which coincides with Ministerial meetings. Module 2 with projects and country reports will be web-based and on the CSLF website and will be updated at least once a year. The Technical Group Executive Committee will propose a revised format for the TRM.

The Task Force on Assessing Technical Issues has four working groups:

- Capture Technologies (United States lead);
- Transport and Infrastructure (Netherlands lead);
- Storage and Monitoring (Canada lead); and
- Integration (Global CCS Institute lead).

In particular, there is good progress in the Storage and Monitoring Working Group, chaired by Stefan Bachu with substantial resource support from Norway. The Transport Working Group needs a new Chair. Discussions about compression are being considered, but it is unclear whether this should be in the capture or transport working group.

The Risk Assessment Task Force endorsed the work plan for a new Policy Group/ Technical Group Task Force on Risk and Liability Assessment for Geological Storage of Carbon Dioxide.

The Global CCS Institute asked CSLF to cosponsor a workshop on integration in London, which will be held on 3 November 2011. Several CSLF recognized projects may attend. Invitations to projects are to be sent out Wednesday.

A possible technical workshop on capture may be held in June 2012 in conjunction with the next Technical Group meeting in Bergen, Norway, with a visit to TCM Mongstad. The Technical Group is also exploring the potential for a workshop on transport. The intention is to hold a technical workshop at least once a year.

The Technical Group has set out a five-year plan consisting of 12 Action Plans:

- Action Plan 1: Technology Gaps Closure
- Action Plan 2: Best-Practice Knowledge Sharing
- Action Plan 3: Energy Penalty Reduction
- Action Plan 4: CCS with Industrial Emissions Sources
- Action Plan 5: CO<sub>2</sub> Compression and Transport
- Action Plan 6: Storage and Monitoring for Commercial Projects
- Action Plan 7: Technical Challenges for Conversion of CO<sub>2</sub> EOR to CCS
- Action Plan 8: Competition of CCS with Other Resources
- Action Plan 9: Life Cycle Assessment and Environmental Footprint of CCS
- Action Plan 10: Risk and Liability
- Action Plan 11: Carbon-neutral and Carbon-negative CCS
- Action Plan 12: CO<sub>2</sub> Utilization Options

The plan will be revised and sent out to TG delegates. Technical Group delegates will report back on any additional actions, the most important actions for each country,

coverage by other international organizations and interest in taking the lead on any of the Action Plans. The goal is to complete the program plan for at least one of the actions before Bergen and use this as a template for others.

Daniel Falcons Lins stated that Brazil will soon approach new researchers to participate in Technical Group Task Forces, but is very busy preparing for the Rio+20 conference in June 2012, for which it expects about 50,000 participants.

## **7. Report from the Risk and Liability Task Force**

George Guthrie and Bernard Frois, Co-Chairs, presented the report of this new Task Force and then asked for discussion.

Dr. Guthrie explained the background behind the request from the Technical Group Task Force on Risk Assessment for guidance on what information was needed. He stated that the Task Force on Risk Assessment needed input from the Policy Group on how the technical risks they were looking at related to the financial issues associated with converting these risks into potential liabilities. He also said that the Task Force on Risk Assessment was looking into a number of issues associated with potential technical risks that may relate to liability. This was being considered in the context of technical issues associated with different phases on a project from planning through injection through post-injection to long-term stewardship. In considering the issue, the Task Force on Risk Assessment has reviewed and supports the proposal made by the Secretariat.

Dr. Frois noted that there was discussion in the past on cooperation on this important issue. He said he understood that the new Task Force should link the risks, both financial and technological, to liability. The Task Force on Financing CCS has already achieved significant progress that can be a direct input into the new Task Force. He then stated that the Policy Group Task Force was pleased to respond to the request. He also stated that he wanted to produce a concrete result.

Dr. Guthrie then requested participation in the new Task Force.

After the discussion, Chairman McConnell asked the Secretariat to work with the co-chairs to explore what resources might be available for this project. The Co-Chairs were also asked to put together a communication on requesting input from the Members. Tone Skogen stated that she will take this idea home and will report back. The Co-Chairs were also to identify within 30 days the types of expertise necessary to carry out this project.

Dr. Frois also stated that the work of the Financial Task Force would continue and that Task Force would hold a workshop on 20 January 2012, in Paris at the offices of Société Générale.

## **8. Follow-up to the Ministerial**

In order to begin the conversation, Chairman McConnell provided some of his take-away insights from the Ministerial Meeting. He stated, most importantly, that the Ministers are committed and the stakeholders want this global CCUS venture to succeed. He further summarized the discussion:

- Ambassador Jones of the IEA said that dependence on fossil fuels will continue, and so will the growth in CO<sub>2</sub> emissions, if unabated. The need for CCS – and CCUS – will be critical if we are to abate these emissions. The graph from Ambassador Jones' presentation showed the role of CCUS. In addition, we need to pay more attention to capture from industrial sources. CCUS is also not just about coal; it must also be applied to natural gas combined cycle plants.

- The shift from CCS to CCUS is well accepted, but a good definition of CCUS must be developed. (The stakeholder definition is a good start.) It is also clear that not everyone has the same utilization opportunities (i.e., EOR).
- From Secretary Chu of the United States: Considerable innovation is taking place; opportunities for further innovation abound. The key question is how do we collaborate to accelerate and exploit those opportunities?
- We are not on track to build the necessary demonstration projects. Too many good proposed projects are being cancelled.
- From the Global CCS Institute: Many projects are still in the pipeline; we need to make those succeed.
- Large investments are needed for demonstration projects from both the public and private sectors, but there are huge barriers. Governments will not pay the entire price tag.
- Legal and regulatory frameworks for CCUS need to be developed. We heard from industry again and again that regulatory certainty is needed. Another issue mentioned repeatedly was liability for stored CO<sub>2</sub>.
- We all need to work together. Collaboration to develop the technology for everyone is important.
- CSLF Members have much in common, but there are clear differences in our situations and approaches. That is good; we can learn from each other.
- We need to let the public know that CCUS is safe, but getting that across can be difficult. Successful and fully transparent demonstration projects we can point to are essential to that communication.
- We heard a lot about the problems; we heard some ideas about solutions; we did not hear about agreed-upon solutions. How can we get to those solutions? What is the role of the CSLF in moving to those solutions?

Delegates were asked for their impressions and what those mean to the future work of the CSLF. Bernard Frois stated that the problem is large, but the idea is to break a large problem into smaller problems.

Observers were also invited to make comments:

- Tony Wood, Clinton Foundation: It is important to find a way to move forward with work that is both high risk and low return until commercial incentives are adequate.
- Andrew Paterson, CCS Alliance: CCS and CCUS can achieve commercial parity and the capacity is available.
- Dietrich Gross, Jupiter Oxygen: Consider monitoring any CO<sub>2</sub> that might reach the surface.
- David Wendt, Jackson Hole Center for Global Affairs: Emissions standards for CO<sub>2</sub> are important.
- John Lyman, Atlantic Council: Be sure to involve NGOs in the process.

**9. New Business**

Chairman McConnell asked if there was any new business.

Muzi Mkhize of South Africa raised a question about whether nitrogen could be used for Enhanced Oil Recovery (EOR). Mr. McConnell responded that, in his experience, it was used under different conditions. Daniel Falcon Lins of Brazil stated that EOR has been in use in Brazil since the mid-1980s and that Brazil would be glad to discuss its experience on the matter with South Africa.

**10. Closing Remarks**

Barbara McKee thanked her direct and indirect staff on the CSLF Secretariat, the Ministerial Steering Committee, Chinese colleagues, and Chairman McConnell.

Trygve Riis stated that he, as Chairman of the Technical Group, and the Technical Group Executive Committee had good support from the Secretariat and thanked the Secretariat for that support.

Li Xin, on behalf of China as host country, thanked colleagues for support in making the meeting successful and useful and wished participants a safe trip back home.

Chairman McConnell stated that he saw leading the CSLF forward as a personal obligation and a privilege. He took note of all the work that needed to be done and stated that it is a privilege to represent our countries moving CCUS forward. He believed that the Ministerial created momentum for the CSLF. Mr. McConnell thanked the participants and wished them a good trip home.

**ACTION ITEMS ARISING FROM THE  
JOINT MEETING OF THE POLICY GROUP AND THE TECHNICAL GROUP**

Item	Lead	Action
1	Communications and Public Outreach Task Force	Follow up on best practices on communications on CCS.
2	Members	Provide names of public affairs professionals to Secretariat.
3	Task Force on CCUS in the Academic Community	Set responsibilities for the next steps on CCUS in the Academic Community.
4	Risk and Liability Task Force	Request input from Members and explore available resources.
5	Risk and Liability Task Force	Identify what expertise is needed for this Task Force.
6	Members	Consider participation in Risk and Liability Task Force.



**POLICY GROUP  
TECHNICAL GROUP**

**Report on the Workshop on Risk and Liability  
of Geologic Storage of Carbon Dioxide**

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## CSLF IS GOING GREEN\*

### REPORT ON THE WORKSHOP ON RISK AND LIABILITY OF GEOLOGIC STORAGE OF CARBON DIOXIDE

*Note by the Secretariat*

#### Background

The CSLF, in collaboration with the International Energy Agency and the Global CCS Institute, conducted a workshop in Paris on July 10 and 11, 2012 to improve understanding of geological risks associated with CO<sub>2</sub> storage and their relationship to financial liabilities. This information is needed by governments to make decisions on liability management frameworks and by industry to make investment and operating decisions. The workshop also discussed how risk and liability information can be communicated effectively. The outcome is this report.

Unclear financial liability for geologic storage, particularly in the long-term, post-closure project phase, can be a barrier to investment in Carbon Capture Utilization and Storage (CCUS) in many jurisdictions. Such financial liability depends, in part, on the geologic risks. Recognizing this interdependence, the Technical Group Risk Assessment Task Force (RATF) asked the CSLF Policy Group for guidance on what information should be provided by geoscientists in order to address financial liability. This workshop was conducted in response to that request.

Attendance in the workshop was by invitation only and included experts from around the world with diverse backgrounds required to address geologic storage risks and liabilities and their relationship. The agenda allowed ample opportunity for discussion, and all attendees were encouraged to contribute to all discussions. The agenda included sessions on each of the issues and perspectives necessary to address the relationship between risk and liability.

#### Action Requested

The Policy and Technical Groups are requested to consider the report and recommendations from the Workshop on Risk and Liability of Geologic Storage of Carbon Dioxide.

\* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.

**Report of the  
Workshop on Risk and Liability of  
Geologic Storage of Carbon Dioxide**

**Paris, France, July 10 and 11, 2012**

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## EXECUTIVE SUMMARY

This report is a summary of the Workshop on Risk and Liability of Geologic Storage of Carbon Dioxide (CO<sub>2</sub>) held in Paris, France on July 10 and 11, 2012. The relationship between the risks of geologic storage and the financial liability of those conducting such storage is critical to the commercialization of Carbon Capture Utilization and Storage (CCUS).

The purpose of this workshop was to improve the understanding of geological risks associated with CO<sub>2</sub> storage and their relationship to financial liabilities. This information is needed by governments to make decisions on liability management frameworks and by industry to make investment and operating decisions. The workshop also discussed how risk and liability information can be communicated effectively. After an opening session to set the scene of the broader issues, six substantive sessions were held.

### Session 1: Introduction and Scene Setting

Senior representatives of the three sponsoring organizations defined the broader issues and related those to the overall context of CCUS deployment. They made several key points:

- Deployment of CCUS is a critical global need.
- CCUS deployment faces significant business challenges.
- It is vital to balance risks and opportunities in order to ensure deployment.
- Progress toward CCUS deployment is too slow, but can be put back on track.
- Risk communication is critical.
- Information on geologic risks is needed for liability decision making.

### Session 2: Geological Risks

This session addressed how geologic risks are measured by geologists and geological engineers. Several presentations addressed how geological risks are estimated in different regions, the current state of knowledge about the risks of geologic storage, and how these risks vary by region. This was followed by an open discussion of the issues. Comments participants made in this session included:

- Geoscientists have a specific definition of risk that multiplies the probability that an event will occur with the consequences of that event. Liability may occur if a consequence is considered a harm.
- Risk may change as a function of time and is partly a function of the pressure in the underground formation into which the CO<sub>2</sub> is injected. Risks are expected to increase with pressure during injection and then level off. Once injection ceases, the pressure decreases and risks diminishes. This relationship, however, may not occur if existing wells penetrate the storage formation.
- Risks and initiatives to address them differ regionally. In Australia, many risk assessment have been conducted in different formations. North America has different risk issues from elsewhere in that millions of oil and gas wells have been drilled, Enhanced Oil Recovery (EOR) with CO<sub>2</sub> has been found to have high potential and much of the subsurface is privately owned. In Europe, a large share of the injection may take place under the ocean. In China and other developing countries, risk assessment is in an early stage of development.

- While much is understood about geological risks, geology is complex and the current state of knowledge has limitations, including in the understanding of:
  - Long-term storage behavior;
  - Interaction of different storage facilities;
  - Induced seismicity; and
  - How risks interact, especially in non-EOR situations.
- Work to improve the state-of-the-art of geologic risk assessment is taking place globally.
- Methods are available to mitigate actual geologic risks, for example, for stopping any leakage.
- Public perception of risk is very different from the actual risks as geoscientists estimate them. The public tends to focus on low-probability but high-consequence events.

### Session 3: Industry Perspective

This session addressed business risks and potential liabilities, how these are evaluated for business decisions and what this means to the different industries. An open discussion followed brief presentations. Comments made by participants included:

- Risk analysis and management must cover the entire project life cycle from pre-injection, through injection and closure to post-closure. Mitigation plans must be in place before injection starts and must have two key aspects, the prevention of leaks and containment in the event of a leak.
- Many independent safeguards need to be in place, some of which are passive and always in place, and others that are active and only implemented when they are needed.
- Risk analysis is an inherent part of site characterization and selection. The total level of risk needs to be low enough with adequate safeguards in place or available to make a site acceptable.
- From a business perspective, liabilities cannot be either unlimited in size or indefinite in term.
- Electric utilities have to deal with many risks as part of normal operations. As they gain experience with the risks related to CCUS, they will learn to manage those risks.
- Regulatory risks are always greater when regulatory frameworks are immature. Some regulators do not yet understand the complexities of CCUS.
- The value chains for CCUS and how these will allocate business risks have yet to be developed.
- International standards for CCUS may help develop confidence in CCUS
- Creating public support for CCUS will be a challenge and the security of geologic storage is just one issue. Trust and credibility by those involved in CCUS is critical to public support for CCUS.
- While most liabilities during project operation are insurable, the post-closure period is not; liability needs to be transferred to the government during that phase.

### Session 4: Economics of Liability

This session considered liability for geologic storage, how risks are valued and how the industry insurance and banking sectors address liabilities. A discussion followed scene-setting speakers from industry, government, insurance and investment banking. Points made by participants included:

- The probability of leakage from a properly-selected storage formation is not great and, if there are leaks, there are ways to deal with them. EOR with CO<sub>2</sub> is better understood and has lower costs than geologic storage without EOR.

- Methods exist to quantify the potential financial damages from geologic storage and can be used for industrial, financial and regulatory decision making.
- Geologic storage must be treated as a business. If CCUS is high risk and low return, it will not be viable.
- How the financial risks are allocated the CCUS value chain has not yet been determined, in part because how the commercial value chain will be organized has not been determined.
- The market for insurance coverage during the operational phase of storage has developed just recently and premiums are coming down.
- The insurance industry can cover many aspects of geologic storage, but no insurance coverage will be available for long-term, post-closure storage.
- When injection is taking place, money is coming in to the project to cover liabilities. When injection stops, however, the money stops. Whatever is done to mitigate risk after that has to be financed from money that was set aside earlier.
- Investors will not now finance a large CCUS project, but perhaps will in the future. Lenders will not take unquantified liability risks on storage.
- There are operators who will store CO<sub>2</sub> underground and get paid for that.

#### Session 5: Government and Policy Responses

This session addressed government policy, the issues encountered by governments in addressing liability and their approaches to risk and liability. Discussion followed speakers from several governments and multilateral development banks. Comments made by participants included:

- Governments throughout the world are working to address issues of risk and liability, each in a way that reflects local circumstances and legal-regulatory frameworks. Different countries have different appetites for taking on the risks of CCUS projects.
- While multilateral development banks have not yet been asked to fund CCUS projects, they have high environmental standards and are working with their client countries to build capacity and assess opportunities. Issues of long-term liability will have to be addressed in any projects they finance.
- Standards should promote efficiency and reduce costs. The motivation should be to demonstrate to the financing community what the future economic value will be.
- Liability relief is a form of subsidy, but it is a very modest one.
- If the carbon price were right, we would have no problem getting CCS projects financed. The perception that you might lose all the CO<sub>2</sub> and face the prospect of losing everything you were paid in the form of allowances for storing the CO<sub>2</sub> is astonishing.

#### Session 6: How Safe is Safe Enough?

This session pulled together the different strands of the previous discussion AND was divided into two parts. The first part addressed what will make the public be and feel safe and comfortable with CCUS. The second part addressed what will make investors comfortable. Comments made by participants included:

- Public acceptance is a challenge and so is risk communication about geologic storage. “Safe enough” is what people believe is safe enough. Still, it is important to communicate what we understand about risks and to convey the benefits of CCUS, for example, jobs. Engage communication professionals. Words matter and precise words matter most.

- It is important to be transparent and have dialogues with both the public and regulators to show that any risks are manageable.
- Most public expectations about an “acceptable” leakage rate are for essentially no leakage. To date, no leakages have been reported and it is important to keep it that way, but CCUS will be judged on its worst performers.
- There is no unique “public.” Sometimes it is the public at large; other times, it is just those impacted by a specific project site. For now, we can primarily focus on specific regulators and communities.
- NGOs are very well trusted by the public, more so than industry and governments. Environmental NGOs have diverse views about CCUS, some based on opposition to fossil fuels. NGOs can be invited to help advance CCUS, but many probably cannot be won over.
- Some CCUS proponents have different interests. It’s hard to get to a common message. If CCUS proponents do not have a common message they will lose to opponents.
- The only good answer to the question of what will make investors comfortable is “perfectly safe. There will be no earthquakes, no leaks, no aquifers despoiled.” We must strive for excellence.
- Risk and liability issues don’t matter unless there is an assured revenue stream. Energy companies deal with risk every day. They are highly professional in this.
- Geoscientists can provide needed information on which to base investment decisions, for example, for permitting, performance improvement, de-risking storage and reducing cost.

### Recommendations

Based on the discussions in the workshop several recommendations can be made:

- Organizations involved in the workshop should take all opportunities to highlight that, based on research and current experience, risks associated with storing CO<sub>2</sub> can be managed.
- Conduct another workshop on risk and liability in the Asia-Pacific region.
- Continue and expand capacity building for regulatory institutions.
- Consider the role of international or national standards for geologic storage of CO<sub>2</sub>.
- Conduct a dialogue with the insurance industry about coverage for geologic storage.
- Consider ways to enhance and support public outreach on geologic storage.
- Government and industry should conduct further research, development and demonstration to resolve remaining technical uncertainties in geologic storage.

## 1. INTRODUCTION AND BACKGROUND

This report is a summary of the discussions and conclusions from the Workshop on Risk and Liability of Geologic Storage of Carbon Dioxide (CO<sub>2</sub>) held in Paris, France on July 10 and 11, 2012. This workshop was convened jointly by the Carbon Sequestration Leadership Forum (CSLF), the International Energy Agency (IEA) and the Global Carbon Capture and Storage Institute (Global CCS Institute). The relationship between the risks of geologic storage of CO<sub>2</sub> and the financial liability of those conducting such storage is critical to the commercialization of Carbon Capture Utilization and Storage (CCUS). Actual, calculated or perceived risks of geologic storage and the liabilities that result from those risks will be central to the legal framework for CCUS; to business decisions about whether and where to proceed with CCUS projects; and to the design, operation and closure of those projects. The relationship between risk and liability, however, is at present often poorly defined or understood and this, in itself, adds its own layer of risk for CCUS project developers and public policy decision makers.

The importance of liability has long been recognized. The CSLF-IEA recommendations to the G8 developed in November 2007 and approved by the G8 heads of state in July 2008, for example, contained the following recommendation regarding liability, which it recommended be completed by 2010:<sup>1</sup>

### **b. Long Term Liability: Priority – 2010**

A framework addressing liability is required for the injection and post-injection phases of a storage project. This includes, but is not limited to, sub-surface property rights, joint liability where there are several operators injecting into the same formation, processes for assessing and resolving potential conflict between CO<sub>2</sub> injection and hydrocarbon production, transboundary movement of CO<sub>2</sub>, and timeframes associated with liability.

7. *Governments should clearly define a liability regime for the operational, closure and post-closure phases of a storage project. The regime should also address:*
  - *Government assumption of long term liability to Governments for the post-closure phase.*
  - *The timing of the transfer of liability to Governments for the post-closure phase.*
  - *Implications for surface and sub-surface transboundary movement of carbon dioxide.*
8. *Governments should develop clear licensing and permitting systems for storage projects. Such regulations should address procedures and responsibilities to ensure safe closure and provisions for post-closure monitoring, and remediation, if necessary.*

Since those recommendations were made nearly five years ago, progress has been made in defining geologic risks and in promulgating legal and regulatory frameworks for liabilities caused by those risks. Yet, in many jurisdictions throughout the world, these frameworks are far from complete or even absent while the public debate about CCUS continues. The recommended completion date in the recommendation above was clearly not met. A result is that, not knowing the full range of possible financial consequences, potential developers of CCUS projects involving geologic storage are hesitant to undertake those projects.

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<sup>1</sup> CSLF and IEA, “Results from the Calgary Workshop, November 27 and 28, 2007, 3<sup>rd</sup> Workshop, Near-Term Opportunities for Carbon Capture and Storage,” December 2007.

One reason why liability frameworks have not been implemented is that the public and government decision makers may not be fully informed of the state of scientific knowledge and engineering capabilities regarding geologic storage of CO<sub>2</sub>. At the same time, the geoscientists who produce that information may not be fully aware of how best to convey their findings to the public or to policy decision makers. Indeed, this workshop was held at the request of the CSLF Risk Assessment Task Force, which is composed of geoscientists, and which wanted to know how it could best produce information of use to policymakers.

## Workshop Objectives and Structure

In order to address those concerns, on July 10 and 11, 2012, the CSLF, IEA and Global CCS Institute jointly held a Workshop on the Risk and Liability of Geologic Storage at the offices of the IEA in Paris, France. The purpose of this workshop was to improve understanding of geological risks associated with CO<sub>2</sub> storage and their relationship to financial liabilities. This information is needed by governments to make decisions on liability management frameworks and by industry to make investment and operating decisions. The workshop also discussed how risk and liability information can be communicated effectively. The outcome is the present report.

Attendance was by invitation and included experts from around the world with diverse backgrounds required to address geologic storage risks and liabilities and their relationship. The 62 participants included representatives of governments, industry, academia/research, multilateral institutions, law firms, financial institutions, NGOs and consulting firms. The agenda allowed ample opportunity for discussion, and all attendees were encouraged to contribute to all discussions.

After an opening session which set the scene of the broader issues, six substantive sessions were held:

- Session 2. Geological Risks
- Session 3. Industry Perspective
- Session 4. Economics of Liability
- Session 5. Government and Policy Responses
- Session 6. How Safe is Safe Enough?

In addition, prior to the workshop, several background documents were sent to each of the participants.<sup>2</sup> Each session had several short presentations to provide a framework for the issues followed by discussion open to all participants. Presenters were encouraged to keep their presentations short and were given the option of not using PowerPoint slides.

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<sup>2</sup> These documents were: Carbon Sequestration Leadership Forum, “Risk Assessment Task Force, Phase 1 Report,” November 2009, which provides a geosciences perspective on risk assessment for geologic storage of CO<sub>2</sub>, including methodologies used for risk assessment; Industrial Economics Inc., “Valuation of Potential Risks Arising from a Model, Commercial Scale CCS Project Site,” February 2012, which is an assessment of the potential financial damages from a proposed carbon capture and storage project; International Energy Agency, “Carbon Capture and Storage Legal and Regulatory Review, Edition 2,” May 2011, which is an overview of the status of legal and regulatory frameworks for Carbon Capture and Storage in jurisdictions around the world, with a special emphasis on liability; and West Virginia Carbon Dioxide Sequestration Working Group, “Report to the Legislature,” July 1, 2011. The “Report to the Legislature” is an example of the type of report a government task force may prepare for a legislature considering carbon capture utilization and storage policies. It covers liability and a range of other policy considerations. These documents may be downloaded from <http://cslforum.org/meetings/workshops/paris2012.html>. The report on valuation of risks is also summarized in Appendix C.

## Workshop Scene Setting

Representatives of the three sponsoring organizations defined the broader issues to be addressed in the workshop and related those to the overall context of CCUS deployment. These representatives were:

- Charles McConnell, Carbon Sequestration Leadership Forum
- Bo Diczfalusy, International Energy Agency, and
- John Scowcroft, Global Carbon Capture and Storage Institute.

They made several key points:

Deployment of CCUS is a critical global need. CCUS is a key component in the transition from traditional uses of fossil fuels to a more sustainable global fuel mix. CCUS, however, is not just required for coal-based facilities such as power plants; it is needed for facilities using all fossil fuels. In the United States, for example, the market share of coal in electricity production has decreased from 50% to 39% since 2009. Mostly, that coal-fired power generation has been displaced by natural gas generation. The switch to natural gas reduced CO<sub>2</sub> emissions, but it did not eliminate them. Fossil energy is projected to be a large part of the global energy mix for the foreseeable future. Fossil fuels must therefore become a responsible choice for both the market place and the environment.

In June 2012, the IEA published the third edition of its Energy Technology Perspectives report.<sup>3</sup> This 700-page report examines several long-term scenarios (through 2050) for the development of a broad range of energy technologies needed in every sector for globally-sustainable energy. That report considered several scenarios leading to increases in the average global temperature of 2°, 4° and 6°Celsius. The impacts of the 4° and 6° Celsius increase scenarios were extreme and, in the case of the 6°Celsius increase, were globally disastrous. CCS is shown to be vital to avoiding these severe outcomes. The question is not whether we deploy CCS, but how.

CCUS deployment faces significant business challenges. Among these challenges are:

- The large investments required in each project and correspondingly large risks;
- Budget challenges facing governments planning to co-invest in CCUS demonstrations;
- Integration of the CCUS value chain and allocation of risk along that value chain; and
- Incompleteness of the legal-regulatory framework for CCUS, including liability.

The issue of risk is central to the business case for CCUS. Important questions must be addressed. Why would anyone take on the risk of investing in CCUS? What sort of limitations on risk would I require? How do we assess risk, and how do we manage it?

It is vital to balance risks and opportunities. There needs to be a different way to consider risk as it relates to CCUS. The usual way people think about risk is just to consider the downside, but there also is an upside, which is the value that CCUS creates. Enhanced Oil Recovery (EOR) is one way to create that value. The United States made an effort to use EOR as a means of providing value for CCUS. A few years ago, it was estimated that opportunities in the United States for using CO<sub>2</sub> for EOR were limited. The U.S. Department of Energy, however, studied that more closely through its various research laboratories and extended its estimates from 15 to 20 years of CO<sub>2</sub> storage capacity from EOR to more than 100 years. It is now estimated that EOR onshore can provide up to 40 percent of U.S. oil demand,

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<sup>3</sup> International Energy Agency, *Energy Technology Perspectives 2012: Pathways to a Clean Energy System*, OECD, Paris: June 2012.

with the possibility that even more could be supplied offshore. The question now being raised in the United States is whether CO<sub>2</sub> can be made available to all those EOR formations. While not all countries will have similar opportunities, some will, and all must look for ways to create value from CCUS and offset risks with opportunities.

Progress toward CCUS deployment is too slow, but can be put back on track. Many of the technologies needed to address climate change are on track for timely deployment; this, however, is not the case for CCUS. Even so, there are still ways for getting it on track. One absolute necessity is to develop a legal and regulatory framework that gives some security to investors. Progress towards such legal frameworks varies by country.

The IEA has updated its 2010 Technology Roadmap for CCS.<sup>4</sup> That Roadmap proposes to implement needed legal-regulatory frameworks in OECD countries by 2020 and in non-OECD countries by 2030. Means of resolving liability concerns needs to be a key element in these legal frameworks.

Risk communication is critical. It is important to answer the public's questions simply and honestly. Try to answer these questions your neighbors may ask: "Will the CO<sub>2</sub> leak?" We need to be able to answer, "No." If they ask: "Is it safe?" we need to be able to answer "Yes." By analogy, if an expert on bridges is asked if a bridge will collapse, that expert could go through long analysis, but the answer needs to be "No." We need, as experts in CCUS, to be in a position to have confidence in being able to answer "No, it won't leak" and "Yes, it is safe." What are the technical issues and how can we communicate these to policy people? This workshop begins the dialogue between the technical and policy communities.

Still, it is important to be careful. As one participant put it: "I used to tell people that the risk of a nuclear disaster was once every million years; but now, after Fukushima, they say that I didn't tell them that this was the year."

Information on geologic risks is needed for liability decision making. While a great deal of work has been done on CCUS by policy analysts, sometimes there is confusion over what risk and liability mean in the context of CCUS. In particular, there are different meanings of the word "risk" as used by different people in different contexts as it relates to CCUS. We hope to understand each other better as a result of this workshop.

## Organization of this Report

Sections 2 through 6 summarize the presentations and open discussion in each substantive session. The summaries of the open discussions consist of comments made by the participants. The purpose is to provide a sense of the discussion. The comments are organized by topic rather than by how they came up in the flow of the discussion. While every effort was made to be accurate, the record of the comments is based on notes taken at the workshop and does not reflect exactly what was said nor who said what. An attempt was been to present all of the viewpoints; in some cases there are disagreements among the views expressed. **The views presented are those expressed by participants in the workshop and do not reflect the views or policies of the Carbon Sequestration Leadership Forum, the International Energy Agency or the Global Carbon Capture and Storage Institute or any of their members.**

Section 7 provides conclusions and recommendations.

Appendix A lists the workshop participants.

Appendix B presents the agenda.

Appendix C summarizes a report provided to participants on the cost implications of risks of CCS.

Appendix D has the PowerPoint slides for those scene setting presenters who chose to use them.

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<sup>4</sup> International Energy Agency, *CCS Technology Roadmap, 2012*, OECD, Paris, 2012.

## 2. GEOLOGICAL RISKS

This session addressed how geologic risks are measured by geologists and geological engineers. In specific, it was to address the following questions:

- What are the geologic risks and local hazards associated with storing CO<sub>2</sub>?
- How can we estimate the magnitudes and probabilities associated with these risks?
- What are the means by which these risks can be managed?
- What are the “known unknowns”?

This session was led by George Guthrie, Chair of the CSLF Risk Assessment Task Force, who gave an overview presentation on the work of this CSLF Task Force. This was followed by presentations by four speakers who discussed how geological risks are addressed in different regions. Taken together, these presentations provide a good overview of the current state of knowledge about the risks of geologic storage including what is known and not known and how this varies by region. The discussion afterward in this session shows the reaction of diverse stakeholders to this state of knowledge.

### Speakers

#### Session Leader

***George Guthrie, U.S. Department of Energy, National Energy Technology Laboratory***  
(See presentation, Appendix D)

The charter of the CSLF Risk Assessment Task Force, established in 2006, was to examine risk-assessment standards, procedures, and research activities relevant to unique risks associated with the injection and long-term storage of CO<sub>2</sub>. These include risks associated with CO<sub>2</sub> near-term (injection) processes (including fracturing, fault re-activation, induced seismicity) and risk associated with long-term processes related to impacts of CO<sub>2</sub> storage. Potential impacts considered by the Task Force include:

- Impingement on pore space not covered under deed or agreement;
- Impingement on other subsurface resources;
- Change in local subsurface stress fields and geomechanical properties;
- Impact on the groundwater and/or surface water;
- Elevated soil-gas CO<sub>2</sub> in terrestrial ecosystems;
- Return CO<sub>2</sub> or other displaced gases (such as methane) to the atmosphere; and
- Accumulation in poorly-ventilated spaces or in low-lying areas subject to poor atmospheric circulation.

The Task Force produced its first report in the fall of 2009. One of the major conclusions of that work was that the link between risk assessment and liability needs to be recognized and considered. It is important to establish clarity in the discussion between the technical and policy communities as well as with potential investors. Such clarity is needed to establish confidence in our ability to demonstrate to all stakeholders that CCUS can be safe and effective.

Geoscientists have a specific definition of risk that relates to the probability that an event will occur and the consequences of that event. In specific:



Geologic risk involves significant interdependencies, which need to be understood. Risks are not independent of one another. Induced seismicity and leakage/migration through a fault are examples of correlated risks. Moreover, efforts to mitigate one risk may have an effect on other risks. In addition both the amount of CO<sub>2</sub> stored and storage capacity are dependent on economics (e.g., a carbon price) and thus risk is also dependent on carbon price.

Many kinds of uncertainties are associated with geologic storage. Some can be managed; others are more random and cannot be managed. Several key uncertainties still need to be addressed:

- The long-term storage formation behavior—does risk truly decrease steadily over time?
- What will be the effects of greater storage in formations in the same proximity?
- How do the uncertainties change over time?
- How big a risk is induced seismicity?

### **North American Perspective**

*Stefan Bachu, Alberta Innovates – Technology Futures*

North America presents different risk issues than the rest of world. Long-term liability is much more of a concern in the U.S. and Canada. Owners of land in the U.S. own everything under their property to the center of the earth. In Canada, the government (provincial in the provinces and Federal in the territories and offshore) owns most of the subsurface. This makes the issue of CCS quite different in these two countries. In both countries, a new development is the production of shale oil and gas through hydraulic fracturing. Shale is often a cap rock for CO<sub>2</sub> storage reservoirs, which may present a future risk for CO<sub>2</sub> development.

Legacy wells are another issue. Millions of oil and gas wells have been drilled in North America, many of which have been mapped or otherwise recorded. In the North Sea, 16,000-17,000 wells have been drilled, but in the U.S., over a million have been drilled in Texas alone, and in Canada the number is several hundred thousand. The assumption is often made that reservoir pressure—and therefore risk—increases during injection and declines after injection ceases.<sup>5</sup> That may not be the case where existing wells intersect the CO<sub>2</sub> storage formation. If these wells cause CO<sub>2</sub> to migrate, risk may actually decrease and then increase again over time as the migrating plume encounters defective wells.

EOR operations, in particular, will occur in regions where there are many existing oil and gas wells. In addition, the requirements of EOR are quite different from geologic storage. CO<sub>2</sub> EOR operations are not transitioning to geologic storage in the United States. Each is subject to a different regulatory agency and must therefore meet different requirements. EOR is subject to state regulation. Geologic storage, on the other hand, is subject to U.S. Environmental Protection Agency regulations, which are much more stringent and expensive to follow. This added burden poses a substantial barrier to using CO<sub>2</sub> EOR operations for geologic storage.

Still another issue is the impact of multiple CO<sub>2</sub> injection operations in the same basin. If someone were to ask today whether CCS is unsafe, and will it leak, the answer would be, “No.” We do not know, however, what impacts one CCS operation will have on other operations. What will happen, for example, 50 years from now, when other CO<sub>2</sub> injections have occurred in that same basin?

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<sup>5</sup> As pictured in the graphic on the previous page.

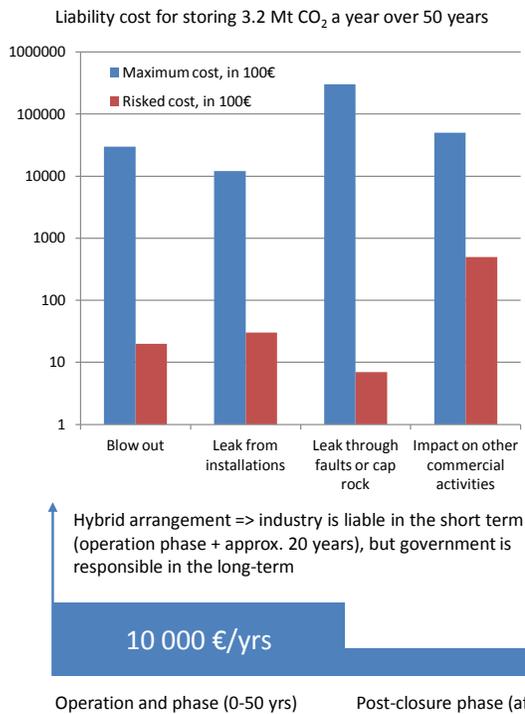
**European Perspective**

*Hallvard Hoydalsvik, Gassnova sp (See presentation, Appendix D)*

Gassnova conducted a probabilistic risk assessment of the Johansen Formation, a deep (3000 m) saline formation in the North Sea. This formation might not be representative of all storage of CO<sub>2</sub> in Northern Europe, but it is representative of such storage facilities in the North Sea. A detailed methodology was used to identify risk factors and calculate the geologic risks and the financial consequences (that is, liabilities) over the life of the project. We calculate frequency and probabilities for where plumes can go. We consider remediation. No old wells are in the area. The risk is from the injection wells and of leakage from the facilities. We assume the owners will bear this risk and that any leakages will come to the surface not just after closing the site, but 200 years later. It will be a slow seepage, not a major leak, and will continue for hundreds or thousands of years, but without much damage in any one year.

The estimated liability is €10,000 per year during the project life and €4,000 thereafter. See figure below. Overall, we think it is safe to store CO<sub>2</sub> in such deep aquifers in the North Sea and other places. Still, even if the risk is low, it may be too much for a business to take on such risk particularly regarding the time perspective of hundreds of years into the future.

**LIABILITY COST DRIVERS**



Category	Potential cost drivers	Estimated timing of occurrence	Liabile stakeholder (suggested)
Blow out	New injection well Killing well Relief well Remediation Fatalities Surrender allowances Halt in operations	0-70 yrs (during operations and transfer, O&T)	Industry
Leak from installations	Remediation Fatalities Surrender allowances Halt in operations	0-70 yrs (during O&T) >70 yrs (through plugged wells)	Industry
Leak through faults or cap rocks	Remediation Surrender allowances Termination of activities New CO <sub>2</sub> -storage	After 220-2500 years	Authorities
Impact on other commercial activities	CO <sub>2</sub> contamination of •hydrocarbon resources •freshwater resources •soil	After 150-300 years	Authorities

**China and Developing Country Perspective**

*Qi Li, Chinese Academy of Sciences (See presentation, Appendix C)*

Three CO<sub>2</sub> geological storage projects are currently in operation in China. Two are for EOR and one stores the CO<sub>2</sub> in a deep saline formation. Various types of health, safety and environmental (HSE) studies were conducted for these projects. In addition, China is conducting research on geologic storage through international cooperation with Australia and the United States. Several Chinese institutes are

involved in HSE associated with CCUS. These include the Institute of Rock and Soil Mechanics (IRSM) of the Chinese Academy of Sciences, the CNPC Chinese Academy of Environmental Protection and the Research Institute of Safety and Environmental Technology.

Lessons have been learned from the experience of analogous storage operations such as acid gas reinjection, enhanced oil recovery and natural gas storage as well as geological storage of CO<sub>2</sub>. We have studied such storage operations in other countries, particularly in Canada.

China IRSM is currently developing a methodology to be used for geologic risk management. This methodology should cover both the geologic space where CO<sub>2</sub> is to be stored and how risk changes over time. It should address various types of risk indicators, for example, local environmental health and safety, ecology, ground and surface water contamination or disruption. Which risk indicators should be included is still being worked on. The recommended methodology so far incorporates several different methods and criteria which should be tailored for different types of geologic storage. Several questions currently remain unresolved, however, in developing this methodology.

## Discussion

The open discussion addressed several different topics ranging from the current state-of-the-art of geologic storage as discussed by the speakers to the difference between public perception and science. Below is a summary of some of the comments made during the discussion.

### Current State-of-the-Art

- A lot of science is being done in geologic risk assessment, but we need to move from the science to engineering.
- The simple  $P \times C$  formulation of risk does not fit complicated sites where different risks strongly interact. More sophisticated risk models need to be developed for those.
- There are places offshore where the consequences of risks are minimal, but from a European perspective we need to look at a broader range of sites.
- Historically, CO<sub>2</sub> was used for EOR because it was naturally available for EOR at low cost. Today some anthropogenic CO<sub>2</sub> is used for EOR. This is important because it shows that EOR use can go forward even where natural CO<sub>2</sub> is not available.
- We oversimplify the risk of storage by just focusing on EOR. We need to consider a much wider scope of CO<sub>2</sub> injections and their interaction with geology. Many stresses will arise from multiple injections, well beyond what we have seen from EOR. While we can say that CO<sub>2</sub> risks from EOR injections are not great, we need to consider CO<sub>2</sub> injections on a much larger scale.

### Risk Mitigation

- We have experience with producing water from geologic formations that are above the storage formation as a way of stopping leakage, and it works, at least on a short-term basis.
- One company involved in several CO<sub>2</sub> injection operations engaged an independent expert organization to assess risks by identify probabilities and consequences. It identified a number of technical risks, but the company identified and implemented safeguards to reduce the probability of those events. Ultimately, however, the risk that it could not reduce was regulatory. Its projects are experienced delays due to regulatory risk.

Risk and Opportunity

- Maybe we should call this workshop: Risk, Liabilities and Opportunities. If we don't see the opportunities, we can tie ourselves in knots worrying about risks and liabilities.
- Why would you risk something? Because you can make a profit.
- How do we combine sustainable biomass and deep coal-bed methane recovery with CCS? It is worrisome that so much emphasis is on risks and liabilities without considering the opportunities.
- Countries with a lot of experience with oil and gas production have more confidence about the safety of such operations.

Public Perception vs. Science

- The public tends to focus on low-probability but high-consequence events, such as the oil well spill last year in the Gulf of Mexico. We should differentiate between our engineering approach, and the public perception of risk. Public perception, however, may affect policy makers and insurance companies.
- We cannot control the public perception of risk. As with hazardous waste, we cannot guarantee that no leakage would occur. The technical risks are minimal, but liability may be based on public perception. Private companies are not going to manage this.
- The risk of something happening and the fear of something happening are different. Who is our voice to respond to public fear?
- We need more projects and technology deployed to show people CO<sub>2</sub> storage is not so dangerous. Independent validation also helps.
- You may talk to the public, but from time-to-time something that is highly publicized will happen to dramatically change their impression. The event does not even have to be local. When a seismic event occurs someplace else, we get questions from the public in areas where seismic events have never happened. So communicating about CCS is not just a one-shot effort and it is not just communicating about your own projects. What some third party does can affect your project and how you need to communicate about it.
- Risks as seen by whom? From a practical view point, we can say leakage risk is small, and it is safe, in comparison to other oil and gas operations. But how will your wife react when she finds out that stored CO<sub>2</sub> is under your house?

### 3. INDUSTRY PERSPECTIVE

Participants were asked to address the following questions in this session, moderated by John Scowcroft of the Global CCS Institute:

- What are the business risks and potential liabilities arising from geologic storage?
- How are the business risks and liabilities of geologic storage evaluated for investment and operating decisions?
- What do these mean to the different industries involved in geologic storage?
- How are similar very long term risks and liabilities addressed in analogous operations?

There were two presentations to stimulate discussion, one from the perspective of the oil and gas industry, and the other from the perspective of the electric power industry.

#### Speakers

##### **Oil and Gas Industry Perspective**

*Bill Spence, Shell (See presentation, Appendix D)*

Shell has attempted to develop or is in the process of developing ten CCS projects. Developing projects for us and others has been fairly straightforward to date in the sense that Company A transports CO<sub>2</sub> through Company A's pipeline to Company A's storage field. The risk is all with Company A. It will become significantly more complicated in the future when there are multiple CO<sub>2</sub> sources, pipelines and storage reservoirs all connected together in a network.

Risk analysis and management must cover the entire project life cycle from pre-injection, through injection and closure to post-closure. Mitigation plans must be in place before injection starts. The plan must have two key aspects, the prevention of leaks and containment in the event of a leak. We need to have a response ready in the event of a leak. Much of the work of managing risks is done before injection begins. Throughout, we need to communicate with the government, regulators and landowners. Each stakeholder focuses on different types of risk.

Many independent safeguards need to be in place, some of which are passive and always in place, and others are active and only implemented when they are needed. Many of those safeguards need to be put in place before a leakage event occurs ("pre-event"). Often, these safeguards are actually natural characteristics of the site and their presence is part of the site selection process. Other safeguards are implemented only if and when an event occurs ("post-event"). We call our detailed assessment of the safeguards before and after a problem a "bow tie" analysis because, illustrated graphically with the event in the middle, it looks like a bow tie.

Risk analysis is an inherent part of site characterization and selection. The total level of risk needs to be low enough with adequate safeguards in place or available to make a site broadly acceptable. Site selection mostly identifies passive safeguards, which are actually characteristics of the site. The characterization of storage formations looks at risks in great detail, often using data from analogous storage operations. During storage site operation, measurement monitoring and verification (MMV) enables detection and response to a problem with effective active safeguards. When enough active and

passive safeguards are in place and the risk is low enough, then we can say, “No, they won’t leak” and, “yes, it is safe.”

From a business perspective, liabilities which are set by legislation cannot be either unlimited in size or indefinite in term.

We did not manage well our relationships with one local community where we planned to inject. A small town was above the storage field. For them, there was no reward from having CO<sub>2</sub> underneath their town. For those ultimately sitting over these storage fields, there is very little risk, but most are unwilling to accept that there is little risk. We learned a valuable lesson: there needs to be a local benefit and we need to explain what we plan to do well in advance.

### **Power Industry Perspective**

*Richard Esposito, The Southern Company* (See presentation, Appendix D)

Electric utilities are sometimes described as risk adverse; but, in fact, we have to deal with many risks as part of our normal operations. Utilities are both risk analytic and risk curious in how we deal with risks. For example, one of the more risky types of facilities we operate is a hydroelectric plant. Think of the damage downstream from a dam breaking and causing flooding. That damage is much greater than what would occur from CO<sub>2</sub> leakage and we are used to managing that greater risk.

As we gain experience with the risks related to CCS, we will learn to manage those risks as well. We are already experienced with some similar risks. For example, many coal-fired power plants are beginning to look like chemical plants as we added complex emission controls—similar to capture. Pipelines for CO<sub>2</sub> are less risky than transporting electricity, but there are some commonalities in managing the flow of a product, whether it be electricity or CO<sub>2</sub>. Similarly, we inject waste water underground, and are comfortable with it. We also store nuclear fuel rods, ash and gypsum for long periods.

Utilities are accountable to a wide range of stakeholder—public utility commissions and the general public. The risk of not having stakeholder support may not kill a project, but it can delay a project. We tell people we are capturing CO<sub>2</sub> and selling to an EOR operator. One problem is false risk perception. For example, this article in a local newspaper:

*“What if the pumping of all this exhaust gas deep underground causes a huge explosion, releasing a noxious toxic cloud of coal gas that gets ignited above ground, barbecuing the surrounding area?”*

E. Downs Green, Gulfport Mississippi, quoted in the Sun Herald Newspaper.

Regulatory risks for utilities are real. Some regulators do not know what to make of the complex permit applications for CCS. Risks are always greater when the regulatory and permitting frameworks are immature. We need to educate regulators and get a dependable framework for going forward. Uncertainties associated with unknown long-term financial risks—beyond the life of a CCS project—pose a barrier.

One question we are asking is how to set up relationships with owners and operators of storage fields. If a CO<sub>2</sub> storage field fails, does that mean the coal-fired plant where the CO<sub>2</sub> is captured has to be shut down? The risks associated with off-site storage will require new business models. Several business models are possible: pay-to-take, team with a storage company, own and operate ourselves. We are trying to learn about which model would work best. To an extent, it depends on whether EOR is a possibility. If it relates to reliability, we want control—we would do capture. For transportation and storage, we might farm it out.

## Discussion

Comments made by participants during the discussion included the following:

### Business of CCS

- It is imperative that industry have the opportunity to earn an adequate return commensurate with the risks it takes on CCS. A profit potential makes a lot of difference on how seriously consider taking risks. If there is not a carrot at the end, why take the risks?
- You can see risks in everything and paralyze yourself; but if you see a potential profit, you are willing to take some risks to make the investment and profit.
- One can challenge the premise that industry will take risks only when there is a potential profit. For example, there is an acid gas (CO<sub>2</sub> and hydrogen sulfide) storage operation near Edmonton, Alberta. It has operated for 30 years, and nobody protests, even though they live near it.
- In the case of electric utilities, what if a power operator delivers the CO<sub>2</sub> to a third party and another party actually stores the CO<sub>2</sub>? Who gets the carbon credits for capturing and storing CO<sub>2</sub>? In the event of problems, who is the liable party? These complexities have not yet been sorted out by industry or policy makers.

### Standards

- What about standards? Are there agreed methodologies on how to quantify risks, and how to identify acceptable mitigation responses? Can we quantify financial exposure, and can we use financial hedging mechanisms, or do we need a physical mitigation method?
- Regulations differ from country to country and jurisdictions within countries. Industry- wide standards may influence regulatory decisions, but they don't have the force of law. Regulators decide.
- We should be pro-active in the development of standards. Having standards is a major advantage in communication. We need to have standards and to defend them vigorously.
- We should develop ISO standards that are broadly recognized, but not developed by any one company, or any one stakeholder. [Note: The International Organization for Standardization (ISO) is already working on developing a standard for CCS.<sup>6</sup> ]

### Trust and Credibility

- It all comes down to a matter of trust. How, as businesses, do you create enough trust to do CCS for many years and for many projects?
- We must ask: how do you generate trust in industry? Public opinion polls show industry and governments are nowhere near the top of those the public trusts. NGOs as well as universities and research scientists are trusted much more. The world does not want to hear industry say CCS is safe. Industry must collaborate with NGOs and regulatory agencies to develop consensus views.
- Industry has a tendency to do exactly what is required but no more. If anything bad happens, it will set the industry back the same way that nuclear accidents set back that industry.
- How do we get approval of the regulator that CCS is safe? We are often running ahead or along with the regulator. We want the regulator to be comfortable that what we are proposing is safe. Absent regulation, do we feel comfortable with the safety of what we are proposing?

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<sup>6</sup> TC 265 Carbon dioxide capture, transportation, and geological storage. See [http://www.iso.org/iso/home/standards\\_development/list\\_of\\_iso\\_technical\\_committees/iso\\_technical\\_committee.htm?commid=648607](http://www.iso.org/iso/home/standards_development/list_of_iso_technical_committees/iso_technical_committee.htm?commid=648607).

- In relicensing a power plant, we engaged the local community—their voices were heard; they became involved and invested in it. They supported the relicensing.

#### Public Opinion and CCS

- CCS has developed a negative profile because some NGOs were opposed to fossil fuels in general, not CCS itself. What we tell newspapers as advocates gets twisted. When the NGOs are against you because they oppose fossil fuel, we don't know what to do.
- Many in industry charge that CCS is an immature technology as a reason not to do it. Industry claims of the immaturity and risk of CCS give lots of ammunition to CCS opponents.
- The kinds of messages that industry conveys are very important. If there is lots of profit, companies get very assertive about the safety of a process that will employ people.
- CCS at a new site is harder to develop than a retrofit at an existing storage facility. Employees can help educate their friends about what is going on with a retrofit.
- Is there a general recognition of global warming? I don't think so. I believe it, but I'm not sure the majority of the people in the world agree.
- What do I say if my wife is concerned? Surveys show women tend to view CCS as more dangerous than men.
- We are caught in a dilemma. We need to execute demonstration projects to be able to point to the data such projects produce. But we can't build more demonstrations because we don't have the data.
- We must paint a different picture around the risk issues, focusing on how CCS will produce jobs and clean energy. We also need to define CO<sub>2</sub> as a valuable product for EOR. When CO<sub>2</sub> is a product, of course, you don't want it to leak or cause seismic problems.
- It's important that we take a strong stand for CCS with the public and with regulators. If we don't take stands, others will hijack the issue. We need to be able to speak from facts and data.

#### Long-term Liability

- There is an injection phase, closure phase, and post-closure phase. We want to be able to show that what we predicted would happen has happened, and then turn over the long-term liability to the government—when we get to the post-closure period. We think the period should be performance-based, rather than a specified number of years.
- How do we make good for leakage—ton-for-ton by capturing CO<sub>2</sub> from another source? Internally, we have calculated the costs of risks and find them relatively low.
- We fool ourselves if we think our businesses are free from contingent liabilities all around us. They all have to be judged against the potential risk. If we want private investment in CCS, we have to limit liability to some extent.
- Liability risk was not created by NGOs. The industry was resisting being forced to capture CO<sub>2</sub>. Some industry lawyers raised the issue, but never specified exactly what risks they were talking about. NGOs took up the concern.
- Most risks are insurable over the shorter term. The government has to ensure for the very long term.

## 4. ECONOMICS OF LIABILITY

This session was moderated by Bernard Frois of CEA, France and addressed the following questions:

- What is the definition of liability in the geologic storage context?
- How are risks valued in various industries?
- What do we know about the liabilities for geologic storage of CO<sub>2</sub>?
- How do the insurance industry and the banking sector assess geologic storage liabilities?

Four speakers addressed various aspects of these issues prior to the open discussion.

### Speakers

#### **CCS Liability in the United States: Examples of Federalism at its Best and Worst**

*Eric Redman, Summit Power (See presentation, Appendix D)*

A number of questions have been raised concerning the safety of CCUS including operational, long-term and health and safety risks. At the same time, there is substantial evidence that CO<sub>2</sub> concentrations in the atmosphere are rising and that climate change is real. Any risks from carbon sequestration need to be balanced against those realities.

Evidence from natural eruptions of CO<sub>2</sub>, such as Crystal Geyser in Utah, which erupts every few hours, indicates that any leak of CO<sub>2</sub> from a sequestration well would not be a hazard to human health. Moreover, the probability of leakage from a properly-selected storage formation is not great and, if there are leaks, there are ways to deal with them. We have had many leaks of natural gas, which is much more hazardous to life than CO<sub>2</sub>.

EOR with CO<sub>2</sub> is better understood and has lower costs than geologic storage without EOR. In North America EOR with CO<sub>2</sub> was originally seen as a temporary bridge to larger CO<sub>2</sub> storage opportunities in deep saline formations. Opportunities for EOR with CO<sub>2</sub>, however, are turning out to be much larger.

We have a “crazy quilt” of differing regulations of CCS in the United States with each state creating its own legal and regulatory framework. This contrasts with nuclear energy, for which there is only one national law governing liability. Attempts to enact CCS liability limits are not likely to be enacted at the Federal level.

EPA regulates anthropogenic CO<sub>2</sub> but not natural CO<sub>2</sub>. Over 90 percent of all oil produced with CO<sub>2</sub> was produced in Texas. The Texas state government approves the injection of CO<sub>2</sub> for EOR and otherwise regulates EOR. For example, Texas has eliminated liability for underground trespass through migration of the CO<sub>2</sub> into adjoining areas. EOR projects get a tax break, but have to conduct monitoring.

Non-EOR storage of CO<sub>2</sub> is treated differently and legislation is being passed in various states to address this. Surface owners are usually paid something up front, and then are paid more if injections are actually

made. Companies such as C12Energy and others are purchasing pore space for future use. Local communities are getting excited about becoming storage areas, much like when wind farms are built.

A consensus is building on state CO<sub>2</sub> liability regimes. The operator of the storage bears liability during injection until the CO<sub>2</sub> plume has stabilized. Most states are willing to assume liability after this and sometimes require fees to create a fund for dealing with leaks. There are forced unitization laws that prevent hold outs from blocking leases of surrounding areas for storage. The operator has liability until it passes to the state.

Insurance is available for all of the risks of operating CCS except for long-term liability after stabilization of the plume. Companies get insurance for hazardous waste storage. Several insurance companies are willing to offer either primary or secondary insurance. This market has just developed recently and premiums are coming down. Site geology is critical to managing risks. The figure below shows how various risks can be addressed.

Risk Phase	Risk Category	Potential Adverse Event	Insurance Available	Geology Critical	State Assumption of Liability
Operations	Transportation	Pipeline Rupture	✓	✗	✗
Operations	Sequestration	Leakage	✓	✓	✗
Operations	Sequestration	Groundwater Contamination	✓	✓	✗
Operations	Sequestration	Induced Seismicity	✓	✓	✗
Long-Term	Post Closure	Leakage	[✗]*	✓	[✓]**
Long-Term	Post Closure	Groundwater Contamination	[✗]*	✓	[✓]**

\* Insurance available following end-of-injection in finite increments; trusts, escrows also possible.

\*\* Several states with comprehensive CO<sub>2</sub> storage rules have some assumption of liability after a period of post-injection monitoring when plume is “stable”

What are the likely damages from a CCS project? A recent report<sup>7</sup> developed an estimate based on publicly-available information for a proposed project in Texas, using a 50-year injection period and a 50 year post-injection period. The expected value of damages was estimated at \$7.3 million of damages, which is far lower than the limits commercially available for pollution legal liability insurance policies for CO<sub>2</sub> storage projects. Appendix C is a summary of this report.

**Estimating Potential Health and Environmental Damage**  
*David Rutland, UK Department of Energy & Climate Change*

<sup>7</sup> This is the Industrial Economics, Inc. report cited in footnote 2 and available for download at <http://www.globalccsinstitute.com/campaign/2012/06/valuation-potential-risks-arising-model-commercial-scale-ccs-project-site>. Appendix C is a summary of this report.

The UK government is offering considerable support for the development and deployment of CCS. In addition to support for R&D, FEED and construction costs the electricity market is also being reformed to incentivize production of all forms of clean electricity including CCS. Legislation has been passed to allow for the storage of carbon dioxide, including unifying the ownership of the seabed for storage purposes. UK has implemented EU CCS Directive. Current UK policy is to limit storage to the offshore area only.

Storage liability is a major issue for those considering investment in CCS. The most significant issue is the liabilities attached to carbon offsets in the highly-unlikely scenario that carbon dioxide leaks from the store to the atmosphere. The avoidance of these offsets will help provide the necessary financial incentives for CCS, but in the highly unlikely event of leakage from the storage site the financial consequences could be substantial. Ultimately, the risks attached to CCS must match the commercial rewards available. This appears not to be that case at the moment. Storage only receives part of the value for CCS, but bears the full consequence of leakage. The value of the risk also likely to appreciate over time in line with the value of carbon offsets. Capture and transportation receive money for their services. If CO<sub>2</sub> leaks after 100 years, the financial risks of that leakage might migrate along the value chain, but the value chain has not been established in CCS. The UK Government has been trying to understand the financial consequences of leakage. The main conclusions are that the major risk is from structures that penetrate the storage formation such as wells. Any leakage can be mitigated using established industry techniques and effectively cap the maximum exposure of the operator. Leakage through faults more of a technical challenge, but for a suitably selected site in the North Sea the probability of significant leakage is negligible.

### **Role of the Insurance Industry**

*John Scott, Zurich Global Corporate*<sup>8</sup>

CCS projects consist of number of discreet, but interlinked activities including CO<sub>2</sub> capture, transport and storage. These are each typically operated by different companies in consortia, each with different appetites for risk. There are also a number of key phases during the life of a CCS project which present different types of risk. When CO<sub>2</sub> injection is taking place, money is coming in. When CO<sub>2</sub> injecting stops, however, the money stops. Whatever you have to do after that point, in terms of funding operations or payments to the State, or other third parties has to be financed from money that was set aside earlier.

The different regulatory and legislative regimes around the world create different liabilities and obligations for CCS operators. In Europe, for example, the CCS and ETS Directives set requirements for surrendering allowances that have to be sold, if any stored CO<sub>2</sub> leaks. In addition operators are also required to set aside "Financial Security" and pay some money through an appropriate "Financial Mechanism" to the "Competent Authority" of a Member State to take over long-term storage liability of a stable CCS site. Regulations and legislation that cover CCS are jurisdiction-specific and therefore there is no "one-size-fits-all" approach for CCS operators. In some places, governments are prepared to accept long-term storage risk, for example, Australia and Alberta; in others, the onus is on the operator, as in Europe. Furthermore, some jurisdictions are more litigious than others and therefore the consequences for operators' liability may require a different funding approach, for example, proposed legislation in the USA (Casey and Enzi, "Carbon Storage Stewardship Trust Fund Act" of 2009).

During the operational injection phase of a CCS project, most risks are manageable through a combination of risk management approaches. These include practical risk management (in the siting, design and operation of the store), contractual risk transfer to parties most able to manage risk and risk

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<sup>8</sup> John Scott is the Chief Risk Officer of Zurich Global Corporate. This article reflects the personal view of the author and not necessarily that of his current employer.

transfer off-balance sheet through self-insured retentions (SIR) or insurance available today in the insurance market. "Standard" property and casualty (P&C) onshore and offshore insurance products would cover many different aspects of the CCS value chain including power generation activities (capture), pipeline transportation (onshore and offshore) and offshore construction, exploration and injection operations. Specialised insurance products, which are not so widely available e.g. CCS liability insurance can also cover particular risks related to CCS such as pollution event liability, business interruption, control of well, transmission liability and geo-mechanical liability.

In the immediate closure and post-closure phases of a CCS project, there are other risk management challenges, such as uncertainty around the final costs of pre-planned activities (decommissioning, monitoring and verification actions). Operators will not be able to transfer these "certain" costs, but would need to separately build up a fund to defray them. This is common practice in the oil and gas and mining industries, but is not currently permissible under the EU CCS Directive which demands "up-front" financial security to be put in place. In addition, in the European North Sea fiscal regime there are currently no tax benefits of decommissioning a CCS project, unlike oil & gas projects that currently benefit from some tax benefits and the opportunity to build up decommissioning funds over time. Insurance can only play a limited role in transferring the risk of cost-uncertainty of some pre-defined decommissioning activities, or cost items, e.g. crane barge hire, through the use of structured financial products [e.g., a Geologic Sequestration Financial Assurance (GSFA) policy]. Again these are not widely available in the insurance market place and only certain insurers would have the ability or appetite to write these covers.

The insurance industry can help with many aspects of CCS, but no insurance coverage is currently available for long-term storage. Many outstanding issues must be addressed before insurance could be considered as an approach to long-term storage risk transfer. These include the multi-year nature of the risk, the difficulty of pricing the risk (unknown future price of carbon, lack of claims experience etc.), the identification of the peril or trigger (how to define when a "leak" has occurred and what the public liability or property damage is). Although innovative risk transfer solutions involving the insurance industry and government could be investigated, significant issues remain such as insurer risk appetite, competition law and commercial viability.

Some work is being done by the insurance industry in the UK through the Climatewise insurance industry association in partnership with the CCSA to address these issues. If these cannot be resolved, then for the CCS industry to progress in the European Union, Member States will have to take the long-term storage risk themselves, or share them (on a limited basis) with CCS operators. Alternatively, if this is not acceptable, then the CCS and ETS Directives may need to be renegotiated and amended.

### **Investment Perspective**

*Axel Wintrebert, Société Générale*

Investors would not be prepared to finance a large CCS project as of today though it does not mean it could not be done in the future. There are kinds of risks a lender would not be willing to take such as unproven technology and insurability which would result into potential unquantified liability risks. Solving these risks is a pre-requisite to financing. Other questions: How does the value chain between capture, transport and storage get organized (regulatory framework and contractual arrangement between companies)? Who captures, who transports, and who stores the CO<sub>2</sub>? How to address CO<sub>2</sub> volume risk that could create huge swings in revenues? Who is going to pay ultimately for the CO<sub>2</sub>? Is the ultimate payer creditworthy?

Cost is an issue. MASDAR had us work on CCS scheme to capture the CO<sub>2</sub> and inject it into oil fields belonging to ADNOC. We had to model the cost of building several capture plants and the cost of

building the transport network to the oil fields. The price to cover all costs and a reasonable return would have to be on average around \$100/ton for carbon. No one is willing to pay that much, so the scheme was greatly reduced.

On top of the technical studies, it is worthwhile to gather lawyers, bankers, and policy makers to consider how to structure a CCS project. We spent quite a lot of time evaluating CCS projects. We concluded in the case of the mandate with MASDAR that segregating capture from transport was the most appropriate solution in terms of risk allocation and flexibility to expand the industry (as opposed to finding someone who would handle CCS as an integrated entity).

The capture and transport sides of CCS should be fairly safe from a technical and insurance perspective. Thus, this part is easily financeable from a liability perspective. Still, there is a big question on the storage. Considering volume risk, we recommended MASDAR to set up a single CO<sub>2</sub> Buyer, in order to benefit from a “portfolio effect”. The Single Buyer purchasing CO<sub>2</sub> from many companies is best placed to mitigate volume risk (upstream) and deliver to the storage company stable CO<sub>2</sub> volumes (downstream).

In conclusion, financing storage is probably not possible for now until issues listed above are resolved and commercial profitability is established.

## Discussion

Comments made by participants during the discussion included the following:

### Government versus Private Responsibility

- If CO<sub>2</sub> migrates into ground water, it carbonates the water, but people are also concerned with other minerals that the CO<sub>2</sub> activates. In the United States, states force you to stop injecting if ground water contamination is detected, and impose fines if the plume has not stabilized. There have been instances in the U.S. of contaminated ground water by substances other than CO<sub>2</sub>.
- You need a way to fund long-term liability by the government. The risks involved in getting CO<sub>2</sub> underground are much less than not storing it. If there are disparities between the risks and benefits, the state should get involved to socialize the costs.
- When does long-range storage begin and insurance end? Tens of years, perhaps beyond the lifetime of the company. Insurance takes effect after a year, with annual renewals. Insurance may get claims for asbestos that are based on insurance policies issued 30 years ago.
- If capture and storage takes place over 50 years, the developer should be liable during that period. In Alberta, the province takes over liability after stabilization of the CO<sub>2</sub> plume.

### Transactions along the CCS Value Chain

- There are operators who will store CO<sub>2</sub> underground and get paid for this service.
- Several questions may be asked. Have you thought about how a storage operator would cover its capital expenditures to take your CO<sub>2</sub>? Will you commit to reliable production of CO<sub>2</sub>? We started thinking about the value chain, based on these questions. An aluminum smelter, for example, would ask if your proposed storage site can be operated without affecting his smelter operations.
- A single buyer would not take onerous liabilities. Is there a mismatch? You are supposed to deliver a certain amount of CO<sub>2</sub> to us; if you don't, you are liable.
- If you have one project upstream and one project downstream, this is a difficult issue. If the volumes of CO<sub>2</sub> are high enough, we can deal with the financing by having one single buyer.

## Workshop on Risk and Liability of Geologic Storage of Carbon Dioxide

- Suppose a power plant that has contracted to provide CO<sub>2</sub> for EOR, but shuts down for maintenance. Will there be temporary storage facilities from which it can provide the CO<sub>2</sub>?
- What about excess layers of cover? What role can hedging play in offsetting some long-term storage issues? A wrap of contracts may create a financeable project.

## 5. GOVERNMENT AND POLICY RESPONSES

Participants in this session, led by Juho Lipponen of the International Energy Agency, were asked to address the following questions:

- What are the motivations behind government policy?
- What issues do governments encounter legislating and regulating risk and liabilities?
- What approaches can governments use to regulate risk and liability for geologic storage?
- Are there lessons to be learned from analogous situations?

Several speakers from different regions and as well as from two multilateral development banks addressed these issues followed by an open discussion.

### Speakers

#### Australia

##### *Ian Cronshaw, Australian Delegation to the OECD*

Australia has been active in supporting CCS through the IEA, the CSLF and the Global CCS Institute. Australia has a number of policies and legislation at both the Federal and state levels to support CCS, for example, the Federal government recently passed a bill to facilitate offshore storage. It recognizes that long-term liability is difficult for a private company to deal with. Once injection ceases offshore, there is a 20-year closure period, and then the Federal government assumes the liability provided that the operator has complied with its obligations.

The Gorgon natural gas field development offshore from Western Australia is expected to cost \$40 billion. However, the gas contains around 20 percent CO<sub>2</sub>. Hence any development plan had to include stripping and sequestration, which is intended to occur below the LNG plant on Barrow Island, off the coast of Western Australia. Liability for long-term storage needed to be addressed. Both state and Federal governments will share the liability 20 years after injection, subject to a number of conditions.

How we treat our uranium mines may also be relevant. A levy is put on the uranium to fund decommissioning. That may be precedent for long-term storage.

Australia just enacted a carbon tax at the beginning of July, literally last week, which is equivalent to €20 per ton of CO<sub>2</sub>. In a carbon intensive economy such as Australia, a major policy move like this was not simple, nor easy, but it will incentivize lower carbon investments.

#### North America

##### *C. Michael Smith, Interstate Oil & Gas Compact Commission (IOGCC)*

The IOGCC is a consortium of U.S. state governors. In 2002, the IOGCC created a task force to study CO<sub>2</sub> opportunities for EOR. The task force produced a report in 2005 that showed large opportunities. A 2007 report by the IOGCC developed model legislation. Some of our states have adopted variations of this legislation.

In 2010, we also completed a study of feasibility of the CO<sub>2</sub> pipeline infrastructure in the U.S. and Canada. This report examined the existing pipeline infrastructure for EOR and considered differences between pipelines for natural gas and CO<sub>2</sub>. Natural gas pipelines cannot be converted to CO<sub>2</sub>, for example, because they are different sizes and require different materials. A lot of the natural gas pipeline rights of way, however, are available for installation of CO<sub>2</sub> lines. This report also considered how state and federal regulations could interface. Lastly, it looked at the business value chain. How can CCS become a money making proposition? It costs about €600,000 per kilometer to build a CO<sub>2</sub> pipeline. It must make economic sense or it can't be done.

We considered “long term” to be 10 years. Operators of EOR operations are liable for 10 years after the end of operations, subject to monitoring.

### ***Gerald Hill, Southern States Energy Board (SSEB)***

The SSEB is a compact commission serving 16 states as an energy advisor. SSEB became involved in carbon management ten years ago and is currently managing two storage fields as demonstration projects. Since 2009 the Cranfield, Mississippi project managed by the SSEB for the DOE's Regional Carbon Sequestration Partnerships have injected and monitored 5.5 million tons of injected CO<sub>2</sub>. About 2 million has been recycled. We are learning a lot about CO<sub>2</sub> storage in an oil field undergoing enhanced oil recovery. We are soon starting operation of an integrated power plant capture and storage operation where CO<sub>2</sub> captured from Alabama Power Company's Plant Barry coal fired power plant will be injected into a saline formation located near Citronelle, Alabama.

We are also looking at CO<sub>2</sub> infrastructure. Where there is an existing CO<sub>2</sub> infrastructure for EOR, CCS has an opportunity to move forward based upon CO<sub>2</sub> utilization and market forces. We are also looking at situations where the CO<sub>2</sub> backbone exists, but you need another pipeline to get to it. There are some states that have storage fields, but no CO<sub>2</sub> infrastructure. We are looking at all three situations.

In the United States, there is an opportunity for implementing policy from the “top down,” from the Federal government, but also an opportunity for “bottom-up” policy development by the states. In the U.S., we don't see anything coming “top down” from the Federal level in the near term. Therefore, we are considering what we can do from the “bottom up” as state initiatives. Let us compare the “no action” scenario with development of CCS projects that are market driven. We see a few states where there is an opportunity for economic development spurred by CCS. We want to maintain the momentum.

## **Europe**

### ***Raphael Sauter, European Commission***

A regulatory framework is crucial for CCS. The EU Directive on the geological storage of carbon dioxide ("CCS Directive") was adopted in 2009 as part of the EU climate and energy package. This Directive establishes a legal framework for the environmentally safe geological storage of CO<sub>2</sub>. As with all EU Directives, it must be transposed into national legislation by all EU Member States. Transposition had to be completed by June 2011.

The overall objective of the CCS Directive is to ensure the safety of CO<sub>2</sub> storage by risk management throughout the CO<sub>2</sub> storage life cycle by including site selection, operation and post-closure. As a first step, a geological formation shall only be selected as a storage site, if under the proposed conditions of use there is no significant risk of leakage, and if no significant environmental or health risks exist. This must be determined by a thorough characterization of the site pursuant to criteria specified in the CCS Directive. For the operation phase, the Directive provides for requirements on CO<sub>2</sub> stream composition,

monitoring, reporting, inspection and corrective measures in case of leakage or significant irregularities. Prior to the transfer of responsibility to the state, all available evidence needs to indicate that the stored CO<sub>2</sub> will be completely and permanently contained. The standard for transfer of liability is hence performance based. Liabilities related to the geological storage of CO<sub>2</sub> are regulated in different legal instruments in the EU. There is a specific EU Directive on environmental liability which covers any damage to protected species and natural habitats, water and land. Liability for climate damage as result of CO<sub>2</sub> leakage to the atmosphere is covered under the EU ETS Directive. If there are any leaked emissions, the operator of the storage site has to surrender allowances. In order to ensure that liabilities can be covered at all times, an operator must show valid and effective financial security before it can begin injections, and the financial security must be periodically adjusted to take account of any changes to site-specific risks and estimated costs. Different instruments and mechanisms may be used to establish the financial security, e.g. deposits, bank or corporate guarantee, insurance. Each instrument has different implications on certainty, flexibility and costs which need to be considered when making a choice on how to establish the financial security. It is up to the Member State to determine the most appropriate instrument and mechanism. Before the transfer of responsibility, a financial contribution needs to be made to the competent national authority; it needs to cover at least 30 years of post-transfer monitoring.

A robust regulatory framework that covers all risks and liabilities is a key element for public acceptance of CCS and a pre-condition for its deployment. Risks for a well-selected, well-operated site should be rather low and equally the potential financial burden for the operator.

#### ***Sergio Garribba, Italian Ministry of Economic Development***

Coal use for power generation is expanding in Italy. Four new coal-fired power plants are under design or in construction in Italy and the government decided that these plants must have room for CCS facilities. Italy identified a national entity for reviewing CCS. We seek involvement of local communities. The European Union has 27 members and we think there should be coordination with other EU members. We assume Europe may want to embrace the same level of coordination as for other elements of cooperation.

There is disagreement in Europe on the cost of CO<sub>2</sub>. It is too low to finance CCS projects. There is a fund for nuclear, and something is needed for CO<sub>2</sub>. There is a project financed by our major electric utility. A 350 MW power plant using coal is being planned, and we are identifying a storage facility. The price of electricity can reflect the costs of CCS facilities.

#### **Multilateral Development Banks**

##### ***Natalia Kulichenko, World Bank***

No country has requested a World Bank loan for a CCS project, but the World Bank is doing capacity building on CCS. World Bank loans are guaranteed by national governments thus hedging Bank financial liabilities for technical or financial non-performance of projects. However, the Bank reputational risk related to non-performance of projects supported by Bank loans and guarantees is taken very seriously..

In the course of assessing projects for potential investment, the Bank considers whether proposed technologies are technically and economically viable. In funding projects the Bank considers operational risks and considers technologies viable that have been in operation for at least 5 years. The Bank adheres to strong environmental safeguard standards. Responsibilities for long-term liabilities are evaluated on a project-by-project basis, and the Bank responsibilities for the project, defined in project legal agreements, typically cover a period of project construction and don't extend until the end of the project life-time (the point, at which long-term liability would start). The Bank doesn't assume long-term liabilities itself, but it

assures that this issue is addressed during the project appraisal process. What will be the potential implications for World Bank lending for a CCS project? Specific criteria have not yet been developed for CCS projects, but specifics on such criteria are yet to be defined due to the fact that there is no experience on lending or providing guarantees on CCS related projects.

*Annika Seiler, Asian Development Bank (ADB)*

CCS or CCUS is in its early stages of development in our region and we have not yet confronted these issues in a real-life situation on any project. ADB has mainly been working with the People's Republic of China (PRC) and recently with countries from South East Asia. Activities mainly focused on capacity strengthening on CCS technologies, knowledge dissemination, identification of barriers, and formulation of strategies to enhance further CCS development. We have not been active in CCS regulatory issues so far. However, we have started working with the National Development and Reform Commission, the relevant apex body for CCS policy making in the PRC, on formulating a comprehensive roadmap for CCS/CCUS demonstration and deployment. ADB sees a necessity for a wider dissemination of the conclusions and report of this workshop especially in key emerging economies of our region such as Indonesia and the PRC. ADB is willing to sponsor such a workshop as part of its ongoing CCS activities in the PRC and could collaborate to organize it.

Looking ahead, ADB is interested in financing a CCS/CCUS pilot or demonstration project in one of its relevant developing member countries. ADB, however, has stringent environmental standards. Any project to be financed will have to be assessed with regard to the environmental risks and comply with ADB safeguard guidelines. The new accountability mechanism and ADB's public disclosure policy allow for stakeholders to comment on proposed loans. ADB cannot finance projects without adequate environmental impact assessment.

We further expect that knowledge institutions and international agencies like the CSLF, IEA and Global CCS institute will provide some key messages and perspectives to confront recent news items that CO<sub>2</sub> storage could trigger earthquakes, which otherwise could prove to be show stopper for CCS.

## Discussion

The following comments were made by participants during the discussion.

### Standards

- Standards should promote efficiency and reduce costs. The motivation should be to demonstrate to the financing community what the future economic value will be. Of course, standards that apply globally can contribute enormously to efficiency. The UN can convene stakeholders to develop standards, without dictating to them.
- The earlier reference to standards was to non-binding standards developed by an industry and stakeholders. It is very important that these be voluntary codes of conduct; standards should not be prescriptive.
- Standards are legally binding, versus guidelines, which are advisory. We need to be careful not to get prescriptive about how CCS projects should be evaluated, planned and operated. Whatever we develop should be "descriptive" rather than "prescriptive."

### Liabilities

- Different countries have different appetites for taking on the risks of CCUS projects.
- The European Commission's CCS Directive had to be transposed to the legislation of member states. It was not difficult to transpose the liability provisions of the Directive.

- Where there is higher density of human population, siting and liability issues become much more difficult. Australia, Canada and the U.S. have the advantage of having large regions without many people.
- Several companies are willing to do storage as a business and take the liability. The risks and liability of CCS can be taken by companies if they see potential for profit.
- We did an analysis of relief from liability for CCS projects, somewhat like what was done for nuclear projects. Liability relief is a form of subsidy, but it is a very modest one.
- China has a draft of CCS regulations, but it is very rough at this stage. We are doing our best to provide a scientific basis for CCS in China.

#### Incentives

- If the carbon price were right, we would have no problem getting CCS projects financed. The perception that you might lose all the CO<sub>2</sub> and face the prospect of losing everything you were paid in the form of allowances for storing the CO<sub>2</sub> is astonishing.
- We put in mandates on renewables and efficiency. CCUS is not helped by mandates. What we need is a carbon price. CCUS is starting to get some traction in the U.S. We see some movement in a few countries. But there should be more on the mandate side if the market isn't working.
- Some countries that are moving ahead have an interest in tapping their fossil fuel resources. The driver for CCUS is not carbon emissions. Those seeking economic opportunity are taking the lead.
- How are renewable energy projects moved? Should CCS have the same status as renewables?

## 6. HOW SAFE IS SAFE ENOUGH?

This session, held on the second day of the workshop, was intended to pull together the different strands of the previous discussion: geologic risks, industry perspectives, the economics of liability, and government policy responses. There were no speakers; the entire session was open discussion after brief opening comments by the session leaders. The discussion, however, was divided into two parts. The first part of the discussion, led by two representatives of environmental NGOs, Paal Frisvold of the Bellona Foundation and George Peridas of the Natural Resources Defense Council, addressed what will make the public be and feel safe and comfortable with CCUS. The second part, led by Barry Worthington of the United States Energy Association, and Francois Kalaydjian of IFP, a French public research organization, addressed what will make investors comfortable. Both parts addressed those issues plus three common questions:

- What geosciences information can create comfort?
- What concepts and approaches for risk communication can be used?
- How can geosciences participate in effective communications?

### **Part 1: What will make the public be and feel safe and comfortable?**

#### ***Paal Frisvold, Bellona Foundation***

In Norway, CCS is a widely known concept which enjoys broad public. How did we get there and what can we learn from this experience?

In the 1990s, Norway was set to not meet its Kyoto commitments and that triggered a search for a way to meet our carbon mitigation obligations. Researchers in Statoil showed there was a possibility to permanently, store CO<sub>2</sub> underground, a measure to avoid paying the Norwegian carbon tax. Thereafter, the NGO community drove CCS promotion to a large extent. In 1997, Bellona suggested to build six gas fired power plants with CCS to meet the rising energy demand in Norway. CCS also became widely known when it led to a fall in a government coalition in 2000.

The petroleum sector is the largest industry in Norway. Many people have confidence in our engineers when they say they can store CO<sub>2</sub> safely. In addition, all storage of CO<sub>2</sub> in Norway takes place offshore, which reduces skepticism and opposition from local residents.

Bellona has drawn up country specific road maps for deploying CCS in Greece, Poland, Hungary and Rumania. Our experience show that we must be concrete and pragmatic in our approach, respecting the economics, politics and culture of each country as CCS will have different opportunities in each country. Additionally, the UK is a good example, where focus has been on job creation in high tech industries leading to increased foreign investments. CCS is also a catalyst for other technologies: Combining sustainably produced biomass with CCS can eliminate more carbon than once emitted, enabling us to reach carbon negative solutions. We need to start now to make this a reality for the future.

By focusing on the many positive aspects of what CCS can bring to the society as a whole, we have a better chance of avoiding an over-emphasis on risk and safety, compared to other similar industrial processes.

*George Peridas, Natural Resources Defense Council*

The Natural Resources Defense Council started looking at CCS extensively about 14-15 years ago. We approached the idea with caution but became convinced by scientific evidence that it could be done safely and effectively. CCS is not our preferred solution: we believe that efficiency and renewable energy should be utilized first, but CCS targets the existing and future fossil-fuelled base and as such is a valuable tool that can greatly help mitigate climate change.

There is no unique public. Acceptance of CCS is context-specific. Sometimes you have to deal with the public at large. In other cases, you don't have to convince the whole world, just those who are impacted by a specific project site. We might have to deal with CCS on a much larger scale eventually. But for the purposes of seeing early projects become reality we should focus on specific regulators and communities.

What do we have to provide to members of the public to make them feel safe and comfortable? More information is not always the solution. Convincing people of the serious threat of climate change does not always entail providing additional scientific evidence. Many people take cues from key thought leaders they trust or adhere to views that conform to their world view. Some communities are inherently comfortable with subsurface operations whereas others are skeptical. An honest, inclusive and open approach is crucial, as is an honest exchange in place of a campaign to "educate".

CCS comes with a burdened label. People have been injecting fluids underground for many years. But some people may still object to injecting CO<sub>2</sub>. People who have been around oil and gas production generally are not afraid of CO<sub>2</sub>. So far, CCS has an impeccable track record. We have had some excellent demonstration projects. One alleged incident recently generated headlines, but it was effectively explained. It is important that this remain so.

A well thought out regulatory framework is important, and we now have that in many countries. Fracking of shale gas formations took off in the United States without accompanying regulation, and should serve as a lesson against letting activities such as these run free without oversight. With CCS, we have largely put the regulatory framework in place first, before broad deployment, and this is wise. We do need, in particular, to think about the liability question however. What will liability relief accomplish? Will it push projects into development? It conflicts with the message and belief that CCS is safe and effective.

## **Discussion**

The following comments were made by participants during the discussion.

### Public Acceptance

- How can we get consensus on CCS and on geological storage in particular? There are two types of consensus: A broad social consensus. This is lacking in most countries. Social consensus on renewables is overwhelming. There is another type of consensus on specific projects by local communities. Local communities can see some of the benefits such as jobs or an improved local economy. This is possible.
- "Safe enough" is what people believe is safe enough. Convincing people that it is safe is hard, especially when everyone can go on the internet and find proponents of what they already believe. At the University of Texas, we are aiming at children whose minds on these issues have not been made up.
- Social acceptance is easier if people get a better idea of what CCS can do for them, keeping their industry viable. It is about engaging the public into believing in a significant technological solution.

The public really has to be engaged in finding the solution. Don't just give them assurances of safety. Let them participate in the discussion.

- Part of what is hindering acceptance is the lack of real CCS projects. We can show it is safe when we have 20 to 30 projects around the world where there have been no problems. It is important for developers to look for good storage sites with local communities that are supportive.
- Trust by the public has to be earned. Yes, there is a question of education, but it gets to the question of process. What you do to deal with safety, is very important. For example, you cannot describe incidents just as accidents.
- A survey was conducted in Saskatchewan, a relatively small Canadian province with a fossil fuel base. Coal provides 77 percent of electricity by a government owned electric company. People are concerned about the environment. Only 37 percent think they know how to fight climate change. In terms of what causes climate change, 95 percent of the population thinks climate change is underway. Most have heard of CCS, but most don't know exactly what it is. Only 39 percent want more electricity from coal, except for coal mining areas of the province. Gender is a factor—58 percent of men and 25 percent of women say they would not be concerned about a nearby CO<sub>2</sub> storage field. Most people know we are storing natural gas in the ground. They are uncertain about how to deal with climate change.
- Would people be concerned about whether CCS would impact their electric bills or would they be willing to pay more? Most people say they will pay more for electric bills for renewables.
- People who are opposed to CCS are opposed to it no matter what and they are usually in places where it will never be built, but the local community where CCS will be built is generally supportive, as long as it doesn't jeopardize them or their groundwater.
- With ground water, you must convince local people that CCS is safe. Regarding the ideologues, I don't think there is anything you can do.
- Some groups are skeptics about climate change and don't see any benefit in spending money to inject CO<sub>2</sub>. A project in Ohio was blocked by a group with this view.
- In many cases, governments speak from both sides of their mouths. The energy ministry may speak in favor of CCS, while the environmental ministry says, "We are not so sure." It is important that government agencies communicate with a consistent voice.

#### Views of the Environmental Community

- If CO<sub>2</sub> is used to get oil out of the ground, some environmentalists are conflicted because they want to stop using oil. But the demand for oil is what it is. If oil can be produced by injecting CO<sub>2</sub>, that's "greener" than developing new oil fields that don't need CO<sub>2</sub> to produce it. I don't get the argument that we shouldn't resort to EOR to produce oil.
- There are a lot of NGOs that are absolutely against CCS. I don't understand. Why do NGOs who want to reduce CO<sub>2</sub> emissions oppose CCS?
- Among NGOs there is a general dislike of fossil fuels. They believe we shouldn't be spending money to support production of fossil fuels. Technically, it might be possible to rely exclusively on renewables, but that is unlikely to happen in the short term.
- Views tend to be shaped by local exploration and production techniques, such as mountain-top removal. They see CCS as a lifeline to keep coal mining going.
- Why should an NGO get interested in CCS? How do you get them involved positively? NGOs choose from a hierarchy of policy issues. Fossil fuel production gets much more subsidies than renewables.

- NGOs differ and they have different views of CCS. We are not helped by industries saying, “we are going to do this.” Some years ago, coal was desulfurized. It was costly, but necessary for public health. The signals we send are not always in the same direction.
- NGOs are very well trusted by the public, higher than industry and governments. Taking carbon out of the atmosphere is a powerful selling point.
- The NGOs can be invited to help advance CCS, but many cannot be won over.

### Industry and CCS

- The methods for monitoring and accounting for injections of CO<sub>2</sub> should be well established. We shouldn’t have to take the word of petroleum engineers and geologist who want to produce oil.
- People can be skeptical about being told that governments and companies can handle all this safely and healthily. Some say, “There is nothing that can possibly go wrong here.” We should acknowledge that things can go wrong, but can be managed.
- Different industries with stakes in CCS sometimes take very different positions on important policy issues related to CCS. Industry needs to have a uniform message about CCS and CO<sub>2</sub>. We have got to do what the NGOs do, and coordinate our message.
- Some CCS proponents have different interests. It’s hard to get to a common message. If we do not have a common message, and rally around it, we are going to get beaten up by opponents.
- How does industry argue for limited liability while arguing that CO<sub>2</sub> is safe?
- We’ve been talking about CCS for coal and the electric industry. But steel, cement and gas processing are also important.
- We looked at CCS deployment through 2050. About 50 percent of carbon reduction could be dealt with by CCS. CCS deployment is very cost effective with some industries other than power in some countries.
- Part of reluctance of some German states to embrace CCS is that they don’t want coal. Germany has heavily invested in renewables, but German industry needs to reduce carbon emissions with CCS.

### **Part 2: What will make investors comfortable?**

#### ***Barry Worthington, United States Energy Association***

The only good answer to this question of what will make investors comfortable is “perfectly safe. There will be no earthquakes, no leaks, no aquifers despoiled.” We are striving for excellence. Earlier, we discussed the notion that CCS has to be safe. We expect everyone to commit to that. How do we communicate that?

If you look at opinion polls, the scientific community is most trusted. We can also mobilize engineers. Engage communication professionals. Words matter and precise words matter most. In the United States, the nuclear industry developed a list of 25 words to use and 25 words not to use. The general public likes “nuclear facility,” but doesn’t like “nuclear plant.” “Nuclear waste” is a bad phrase, but “nuclear material” is a good phrase. We do need a common message. That may come out of this particular workshop.

Safety first. We must impose a culture of safety on the CCS development. When we look at the aftermath of the terrible events at Fukushima Daiichi we see that most of the world still embraces nuclear power. It

is difficult to speak with absolute confidence about safety. Is it safe to continue to emit CO<sub>2</sub> as we have been doing? We also need to consider that.

What will make investors comfortable? Revenue streams. Risks and liability don't exist in a vacuum. There must be a revenue stream. Risk and liability issues don't count unless there is an assured revenue stream.

Energy companies deal with risk every day. They are highly professional in this. They deal with technology risk and financial risk. They are good at handling all kinds of risks except political risks. Ever since the time of Drake in the oil industry and Edison in the electric utility industry, nobody can model political risks. If political institutions decide to control emissions of CO<sub>2</sub>, reducing those emissions will create an assured revenue stream.

*Francois Kalaydjian, IFPEN (See presentation, Appendix D)*

Investors will be made comfortable if an attractive business case is met, a clear and stable regulatory regime is established, technical risks are well managed enabling the public support.

### Economics

Geoscientists can provide information that will give investors comfort, but a business case has to be established. CO<sub>2</sub> must have an attractive value. Currently in Europe, CO<sub>2</sub> has virtually no value, about €7 per ton—nothing, really.

We would like to get a full idea of storage capacity for getting a cost estimate of the tonne of CO<sub>2</sub> stored. The oil and gas industry has some guess about the size of storage capacity, but not perfect knowledge. You start eating the cake, but you do not need to know precisely the full size of the cake.

For CO<sub>2</sub> storage, we would like to know the exact capacity of the storage before we start injection, but we cannot. As for deep saline storage, in particular, you don't know much until you start injections. Yet, it is difficult to find investors who will spend money without better knowledge of potential storage capacity of their storage formation.

### Regulatory Regime

There is need for regulatory certainty. For instance, France is no longer considered as a good country for producing oil and gas companies as for shale gas production the regulatory regime was changed all of a sudden.

Regulatory regimes are not all the same. In Europe, CO<sub>2</sub> storage has to be safe and permanent. There can be no leakage which is not necessarily the case in other regions of the world. What does that mean?

### Risks

We cannot claim there is no risk. It's near zero risk. We have to show we can manage risk in such a way we can be trusted. We need to demonstrate that after 20 to 30 years of monitoring and further 20 years of surveillance there won't be any evidence of possible leakage. What level of inaccuracy can we accept? How to be safe enough? Clarity about these matters will improve with experience.

### Information Provided by Geoscientists

Geoscientists can provide needed information on which to base investments, for example, for permitting, performance improvement, de-risking storage and reducing cost. Storage cost is often claimed to be small compared to capture cost. But there is need for substantial upfront investment. Geosciences can help in

optimizing the economics. Offshore storage is more expensive, but least controversial. Geosciences can also help with communication, for example, showing how the plume will expand over time, which corrective actions or remediation techniques can be developed to solve potential problems that would arise and how safety increases with time. That will be important for allowing the transparent liability transfer from operating companies to public authorities under a regulatory framework.

There are stages in the permitting process—starting with characterization. The aim is to reduce the risk as close to zero as possible. Information from geosciences must be brought to the public during permitting. Geophysics and geochemistry must be used to help develop monitoring and surveillance techniques. Then we have to compare monitoring results with actual data over time. But we rely on numerical models to predict future performance of storage. What will happen in the long term? Geosciences have to improve the accuracy of the numerical models.

One question posed for this session was whether there are relevant examples of effective or ineffective communication for geologic storage ore from other fields. One example of effective communication is the Lacq project of Total in France. Communication for that project took time but was effective.

## Discussion

The following comments were made by participants during the discussion.

### Acceptable Leakage Rates

- In Europe, no CO<sub>2</sub> leakage is acceptable. But currently, we are emitting billions of tons of CO<sub>2</sub>. So compare any possible leakage from storage fields with uncontrolled emissions.
- When people propose acceptable rates of retention, they often say you must prove you will have a 99% retention rate for 1,000 years. Their aim is actually no leakage. That would be very difficult to prove. People up models and argue about what they predict.
- As the “bow-tie” model shows, we have ways to deal leakage if it occurs.
- One storage reservoir we considered turned out to have less storage capacity than we needed, so we switched to using another reservoir. Just plain engineering was required to fix it, and we controlled it. It is the same with leakage.
- Consider how effective we are in storing CO<sub>2</sub>. Today leakage from injected CO<sub>2</sub> is near zero. The EOR projects may recycle some injected CO<sub>2</sub>, but they are different from other purely storage projects due to their economics.
- CCUS will be judged on the basis of its worst performers. So we must not let anything happen. We need some way of controlling any fly-by-night operators who don't follow best practices.
- In the short term we can talk about active safety, and for the long term, passive safety. Fortunately, long-term pressure reductions make leakage less likely over time. In the short-term, there are remedial actions for leakage.

### Analogies to Hydraulic Fracturing

- What is acceptable for hydraulic fracturing for natural gas? Is this a good analogue?
- Shale gas extraction leaks some methane. There has been quite a bit of study of emissions of methane through the process. It is not a good analogue to CO<sub>2</sub> capture and storage. Operators try to mitigate that. Methane is a valuable product and leaking it is like leaking money, so gas producers have a strong motivation to prevent it. There is technology available to handle that.

Regulation

- Markets don't work by themselves. They have to have active oversight and monitoring.
- We must provide clear, transparent information for the regulators – from scientists and NGOs. Without a transparent process, regulators have problems. Many regulators are very happy to do their job if they have good information.

Risk Communication

- We need to communicate what we understand about risk.
- Communication is a big job. Which organization should do it? It's not clear, but this warrants additional discussion. Be very careful who your messenger is.
- It is important to be transparent and have dialogue with the public to show that any risks are manageable.

## 7. CONCLUSIONS AND RECOMMENDATIONS

The workshop brought together experts in different relevant fields to discuss risk and liability of geologic storage of CO<sub>2</sub>. These experts came from the government, industry, NGOs and research/academic institutions. This section summarizes their perspectives and recommends next steps for addressing the issues identified in the workshop.

### Conclusions: A Summary of Key Perspectives

Those attending agreed on the importance of developing CCUS. CCUS is not an option for either industry or society; it is a necessity. CO<sub>2</sub> emissions into the atmosphere are not acceptable to society.

Legal and regulatory measures to clarify long-term liability were seen as vital to the development and deployment of geologic storage. Such measures are being considered in many jurisdictions throughout the world, and each will be designed to fit the specific circumstances of that jurisdiction. Credible institutions are needed in each country to regulate and manage risks.

There was strong agreement that ongoing, informed, accurate and clear communications to the public, environmental NGOs, policy makers and regulators on the safety of geologic storage is necessary. This idea came up repeatedly in every session.

Although more work is needed to resolve remaining uncertainties, geological risks are increasingly well understood and manageable. This, in particular, needs to be clearly communicated.

The safety and security performance of geologic storage projects so far has been excellent. No leakages have been reported. It is vital that this strong performance continue in order to clearly establish the safety and security of geologic storage. Data from multiple projects is needed and industry must be transparent.

Industry repeatedly stated that it cannot have unlimited and undefined liabilities and cannot finance projects with such risks. Insurance companies are willing to cover many of the CO<sub>2</sub> storage risks during the life of a project, but not beyond. Political and regulatory risks associated with undefined liability are a major concern. Industry also needs an upside opportunity for revenue in order to have the incentive to do geologic storage, not just downside risk.

### Recommended Next Steps

Based on the discussions in the workshop, several recommendations can be made, some of which were discussed in the workshop:

- Organizations involved in the workshop should take all opportunities to highlight that, based on research and current experience, risks associated with storing CO<sub>2</sub> can be managed. Such assertions are well supported by the current state of knowledge and experience with CO<sub>2</sub> storage to date and need to be unequivocally conveyed to a broad international audience.
- Conduct another workshop on risk and liability in the Asia-Pacific region. This should be coordinated with the Asian Development Bank and involve representatives of developing countries in the region as well as others. The substance can also build on the findings of this workshop.

- Continue and expand capacity building for regulatory institutions. The institutions that will regulate the safety and security of CO<sub>2</sub> storage and set or implement the terms of financial liability need a full and accurate understanding of geologic storage. Such capacity building is needed in both industrialized and developing countries.
- Consider the role of standards for geologic storage of CO<sub>2</sub>. It has been suggested that such standards could possibly provide guidance for good practices for CO<sub>2</sub> storage and credibility that such storage can be safe and secure. Such standards are already being developed by the ISO.
- Conduct a dialogue with the insurance industry about coverage for geologic storage. It was reported in the workshop that several insurance companies are willing to insure certain aspects of geologic storage during the operational phase of storage. Such a dialogue could address the adequacy of the terms of such coverage and what further role the insurance industry can play.
- Consider ways to enhance and support public outreach on geologic storage. The importance—and current inadequacy—of such outreach was repeatedly raised during the workshop.
- Government and industry should conduct further research, development and demonstration to resolve remaining technical uncertainties in geologic storage. While much progress has been made, uncertainties remain, but these uncertainties can be reduced through further effort and this will further reduce geologic risks. Information on this work should be shared through international organizations such as the CSLF and Global CCS Institute. Such work should also further explore the link between geologic risks and financial damages and how this varies with circumstances.

## Appendix A

### Workshop Participants

<u>Name</u>	<u>Organization</u>
Bachu, Stefan	Alberta Innovates - Technology Futures
Blakeway, Darrell	Bluewave Resources, LLC
Bertucci, Salvatore	Arcelor Mittal
Didier, Bonijoly	BRGM
Cronshaw, Ian	Australian Delegation to the OECD
Cugini, Anthony	DOE National Energy Technology Laboratory
Czura, Maciej	JESSICA and Investment Funds
Day, George	Energy Technologies Institute
de Lannoy, Rose	GDF Suez
de Vigan, Stephanie	Ecole des Mines de Paris
Diczfalusy, Bo	International Energy Agency
Dreux, Remi	GDF Suez
Dybwad, Carmen	IPAC-CO2
Esposito, Richard	The Southern Company
Florian, Federico	KFW IPEX-Bank GmbH
Foster, Scott	UNECE Committee on Sustainable Energy
Frisvold, Paal	Bellona Foundation
Frois, Bernard	CEA
Garribba, Sergio	Italy Ministry of Economic Development
Gerstenberger, Matt	CO2CRC
Guthrie, George	DOE National Energy Technology Laboratory
Hansen, Eirik Harding	Gassnova sp
Heiburg, Sigurd	UNECE Committee on Sustainable Energy
Herer, Clara	France Ministry of Ecology, Sustainable Development and Energy
Hill, Gerald	Southeast Regional Carbon Sequestration Partnership
Hilton, Robert	Alstom
Høydalsvik, Hallvard	Gassnova sp
Kalaydjian, Francois	IFPEN
Kulichenko, Natalia	World Bank
Li, Qi	Chinese Academy of Sciences
Lipponen, Juho	International Energy Agency
McKee, Barbara	US Department of Energy
McConnell, Charles	US Department of Energy
Nekhaev, Elena	World Energy Council
Nicot, Jean-Philippe	Bureau of Economic Geology
Osborne, Victoria	Striker Communications
Paterson, Andrew	CCS Alliance
Peridas, George	National Resources Defense Council
Perrette, Lionel	France Ministry of Ecology, Sustainable Development and Energy
Perrin, Jen-Luc	France Ministry of Ecology, Sustainable Development and Energy

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Podkanski, Jacek	European Investment Bank
Price, Jeffrey	CSLF Secretariat
Raldo, Wiktor	European Commission
Redman, Eric	Summit Power
Rutland, David	UK Department of Energy and Climate Change
Ryo, Kubo	Research Institute of Innovative Technology for the Earth
Sauter, Raphael	European Commission
Scott, John	Zurich
Scowcroft, John	Global CCS Institute
Seiler, Annika	Asian Development Bank
Smith, Michael	Interstate Oil and Gas Compact Commission
Spence, Bill	Shell
Tait, Lachlan	Baker & McKenzie
Treanor, Sinead	ESB Energy International
Wintrebert, Axel	Société Générale
Worthington, Barry	United States Energy Association
Wroblewska, Elzbieta	Poland Ministry of Economy
Zakkour, Paul	Carbon Counts

## Appendix B

### Workshop Agenda

#### Tuesday, 10 July 2012

**8:30 AM Registration**

**9:00 AM Session 1. Introduction and Scene Setting**

Objectives of Meeting and CSLF Perspective

*Charles McConnell, US Department of Energy*

*Workshop Chair and Chair of the CSLF Policy Group*

Welcome and IEA Perspective

*Bo Diczfalusy, International Energy Agency*

Global CCS Institute Perspective

*John Scowcroft, Global CCS Institute*

**9:30 AM Session 2. Geological Risks**

Discussion Leader: *George Guthrie, US Department of Energy and Chair, CSLF Task Force on Risk Assessment*

#### Regional Panel

Australia

*Matt Gerstenberger, CO2CRC*

North America

*Stefan Bachu, Alberta Innovates – Technology Futures*

Europe

*Hallvard Høydalsvik, Gassnova*

Developing Country – China

*Li Qi, Chinese Academy of Sciences*

10:15 AM Discussion

*Participants*

**11:00 AM Coffee Break**

**11:30 AM Session 3. Industry Perspective**

Discussion Leader: *John Scowcroft, Global CCS Institute*

Integrated Oil Company Perspective

*Bill Spence, Shell*

Power Company Perspective

*Richard Esposito, The Southern Company*

12:00 PM Discussion

*Participants*

**Tuesday, 10 July 2012 (Continued)**

**1:00 PM Lunch**

**2:00 PM Session 4. Economics of Liability**

Discussion Leader: *Bernard Frois, CEA and Chair, CSLF Task Force on Financing CCUS*

Estimating Potential Health and Environmental Damages

*David Rutland, UK Department of Energy and Climate Change*

Role of the Insurance Industry

*John Scott, Zurich*

CCS Liability in the United States: Examples of Federalism at its Best and Worst

*Eric Redman, Summit Power*

Investment Perspective

*Axel Wintrebert Société Générale*

2:40 PM Discussion

*Participants*

**3:30 PM Coffee Break**

**4:00 PM Session 5. Government & Policy Responses**

Discussion Leader: *Juho Lipponen, International Energy Agency*

Panel on Proposed Policies & Legislative Approaches

Australia

*Ian Cronshaw, Australian Delegation to the OECD*

North America

*C. Michael Smith, Interstate Oil and Gas Compact Commission*

*Gerald Hill, Southern States Energy Board*

Europe

*Sergio Garriba, Councillor, Italian Ministry of Economic Development*

*Raphaël Sauter, European Commission*

Multilateral Development Bank

*Natalia Kulichenko, World Bank*

*Annika Seiler, Asian Development Bank*

5:00 PM Discussion

*Participants*

**6:00 PM Adjourn for Day**

**7:30 PM Group Dinner**

**Wednesday, 11 July 2012**

- 9:00 AM Session 6. How Safe is Safe Enough?**  
Discussion Leaders: *Paal Frisvold, Bellona Foundation*  
*George Peridas, Natural Resources Defense Council*
- Discussion: What will make the public be and feel safe and comfortable?  
What geosciences information can create that comfort?  
*Participants*
- 10:15 AM Coffee Break**
- 10:45 AM Session 6. How Safe is Safe Enough? (Continued)**  
Discussion Leaders: *Barry Worthington, United States Energy Association*  
*Francois Kalaydjian, IFPEN*
- Discussion: What will make investors comfortable?  
What geosciences information can create that comfort?  
*Participants*
- 11:45 AM Wrap-up and Next Steps**  
Discussion Leader: *Barbara McKee, CSLF Secretariat*
- Summary of Prior Discussion  
Rapporteur: *Jeffrey Price, CSLF Secretariat*
- 11:50 AM Discussion**  
*Participants*
- 12:20 PM Final Wrap Up**  
*Barbara McKee, CSLF Secretariat*  
*Juho Lipponen, International Energy Agency*  
*John Scowcroft, Global CCS Institute*
- 12:30 PM Adjourn Workshop**

**Appendix C**  
**Summary of Report on**  
**Potential Risks of CCS and their Cost Implications**

## Carbon Capture and Storage: An Approach to Understanding Potential Risks and their Cost Implications<sup>9</sup>

Carbon Capture and Storage (CCS) is an important technology that can be used to prevent large quantities of carbon dioxide (CO<sub>2</sub>) resulting from combustion or chemical processing from being released into the atmosphere. CCS integrates three steps: 1) separation (i.e., capture) of CO<sub>2</sub> from the exhaust streams of large sources and compression, if needed, 2) transport of the CO<sub>2</sub> to a storage location, typically by pipeline, and 3) injection of the CO<sub>2</sub> deep underground for permanent storage in a defined geologic formation. Once in that geologic formation, several well-understood geologic trapping mechanisms serve to keep the CO<sub>2</sub> there.



**Figure 1. CCS prevents CO<sub>2</sub> emissions from entering the atmosphere and instead stores the CO<sub>2</sub> deep underground.** Source: Global CCS Institute

The technologies for each of these steps are already used independently for different purposes in several common industries including natural gas refining, oil and gas production, and the manufacture of chemicals. Ongoing work focuses on improving the cost-effectiveness of capture, integrating the three steps, enhancing our understanding of the storage properties of the geologic formations, and providing reliable information for the development of appropriate commercial practices and government policies.

Any well-sited, well-operated CCS operation should have no incident. However, like any industrial operation, CCS has the potential risk for accidents that could lead to damages to human health or to the environment. Some potential types of damages are well understood in a power plant or oil field operation context, such as damages arising from health-related injuries from routine operations. Other potential damages stemming from the possible release of CO<sub>2</sub> are less well understood.

This brochure describes a recent project sponsored by a group of stakeholders involved in CCS to use established financial analysis methods to develop a good understanding of the magnitude, timing, and nature of potential financial impacts of the risks of damages to human health and the environment

<sup>9</sup> This report summary was made available by the Global CCS Institute and Chevron and will be published in brochure form by the Global CCS Institute.

associated with accidental releases from a CCS project. This analysis is intended to help industry make informed investment decisions, to be useful in the further development of laws and regulations governing CCS, and to better inform the public in whose communities CCS projects may be operated.

This analysis will also be useful in considering policies to address the long-term stewardship of CO<sub>2</sub> in geologic formations. CCS projects are long-lived. In a typical large project, CO<sub>2</sub> injection might take place over a 30-50 year horizon and the CO<sub>2</sub> must stay securely in the formation for much longer. Current or proposed regulations in various jurisdictions typically stipulate that responsibility for a CCS project resides with the developer for a specified period of years after injection ceases and/or until it can be demonstrated that certain criteria have been met. After this demonstration, responsibility may be explicitly transferred to a government body. Uncertainty about the ability to make this demonstration in a specified period of time is a significant up front concern for projects. Developers are concerned about the uncertainty of how long they will have to stay active in the project; the public is concerned about who will be accountable if something goes wrong many years out in the future, and project funders worry about the financial risk from this uncertainty. Both CO<sub>2</sub> pipelines and the capture facility must also be operated safely over the entire period they are used.

In an effort to demonstrate how potential financial damages can be estimated, a group of diverse organizations involved in CCS sponsored a project by a leading damages assessment firm, Industrial Economics Incorporated (IEc), to develop and test a method for valuing potential CCS risks. This method applies standard approaches used in the insurance and finance industries for risk assessment. The study estimates the scope, timing, and magnitude of potential financial damages associated with the capture, transport and storage portion of a planned CCS project over a 100-year period, including 50 years of injection and 50 years after the CO<sub>2</sub> injection has stopped. This study estimated the monetary costs to address impacts on people and the environment arising from accidental releases; it did not estimate the potential costs from facility construction or routine operation, nor potential costs associated with impacts to workers, business interruption, facility repair or similar private costs internal to the operator such as legal penalties or lawsuits. The final report based on this study was released in June 2012.<sup>10</sup>

The analytic method was applied to a set of real-world project plans and data, the Jewett, Texas FutureGen 1.0 project. This project was proposed as part of a formal screening process. Although the site was not ultimately selected as the finalist site, a detailed risk assessment was prepared for the final round of consideration. This risk assessment is publicly available and served as the basis for testing the method for estimating potential financial damages from a specific large CCS project. Although the risk assessment was very detailed, it was developed for the first stage of project development: site selection. Additional site characterization work such as drilling test wells and conducting local surveys would take place if the project moved forward for development. This further work would produce additional and more detailed information that would enable more precise estimates of risks and potential damages. Therefore, after careful review, the sponsors of the damage assessment decided that the analysis would use available data from similar industrial processes to develop a reasonable set of assumptions for the few key data types needed for a comprehensive damages estimation mode but not included in the published Jewett risk assessment.

This analysis indicated that the median estimated financial damages from a well-sited, operated, and closed CCS project at this site would be expected to be approximately \$0.15 per ton of CO<sub>2</sub> injected.<sup>11</sup> The final FutureGen 1.0 project was planned in Illinois; it was originally planned to cost roughly \$1.8 billion. Using this cost basis as a point of comparison, the magnitude of expected financial damages would be less than 0.04% of original project costs.

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<sup>10</sup> Industrial Economics, Incorporated, "Valuation of Risks Arising from a Model, Commercial-scale CCS Project Site," Cambridge, MA, June 2012. This report may be downloaded from: <http://www.globalccsinstitute.com/campaign/2012/06/valuation-potential-risks-arising-model-commercial-scale-ccs-project-site>.

<sup>11</sup> The 'upper end' (95<sup>th</sup> percentile) damages estimate was approximately \$0.34 per metric ton.

The approach developed in this analysis, fitted to site-specific circumstances and available data, could be applied to other CCS projects. The types of information generated from this approach will be important to several groups. Project developers will be interested in using it early on to develop order-of-magnitude estimates for use in site selection and project design; later, when more detailed site information is available, these same developers can adapt the model to refine their project design and plan risk management strategies. Legislators and regulators will be interested in this kind of information in overseeing public safety and permitting. The financial and insurance industries will use this kind of information in assessing investment risk and designing financial risk management tools. The public will also use this type of information in assessing proposals for CCS projects in their communities.

### **How Does The Valuation Approach Work?**

The approach developed for this study relies on a standard financial modeling procedure called “probabilistic simulation.” The steps involved are very briefly described here but are presented in great detail in the IEC report. Essentially, IEC constructed a set of spreadsheets and connected them into a cohesive model. This model was used to generate a very large number of scenarios that reasonably capture the range of possible outcomes from the modeled project given the underlying probability distributions and variability in impacts and associated damages. The results of the analysis can be used to estimate the probability that various potential damages amounts will be incurred.

#### **Step 1: Identify Relevant Risk Events**

The CCS risk of greatest concern stems from leakage of CO<sub>2</sub> at the capture facility, from the pipeline, at the injection well, or from the geologic formation deep underground used for storage. If such a “leakage event” occurs, it could result in human health or ecological harm. Extensive work has been conducted to identify the potential pathways for CO<sub>2</sub> leakage. For example, one such effort was spearheaded by the International Energy Agency and resulted in a publicly accessible risk scenarios database for CCS projects.<sup>12</sup> This database contains what is termed “Features, Events, and Processes (FEPs)” related to CCS projects. This database was developed using systems analysis to methodically identify roughly 200 generic FEPs that can be selected on a site-specific basis for use in risk assessment. As discussed in more detail below, this particular application of the model primarily relied on the identification of risk events as presented in a publicly available risk assessment.

#### **Step 2: Estimate Magnitude and Probability of Risk Events**

Standard risk assessments use data from a variety of sources such as equipment manufacturers, historical performance, scientific literature, and site-specific plans to develop quantified estimates of risks. In this case, such data was used to estimate the probability of releases and the likely size of such releases if they occur. These estimates reflect potential ranges of probabilities and sizes of releases. For example, a pipeline rupture could be a small crack that goes undetected for days, thereby releasing smaller amounts of CO<sub>2</sub> over a longer period compared to or a large hole that releases CO<sub>2</sub> at a greater rate but is detected quickly and stopped. Further, the probability of each these types of events may be different. Risk assessments often estimate the expected probability of a rupture or similar event that could cause damage, and the expected amount that will be released. The IEC team created a flexible model that allows for both a range of potential events and magnitudes and probabilities that they will occur. Sampled repeatedly and randomly over these ranges, the model estimates the range of possible outcomes.

#### **Step 3: Develop Cost Relationships Indicating the Range of Potential Costs**

IEC evaluated the effects of the potential types and magnitudes of releases identified in Step 2 and developed cost estimates for addressing them based on valuation methods from legal systems for accident compensation, natural resource damage assessments, and cost-benefit studies. In two cases, costs estimates could not be developed from real-world case studies: the cost of CO<sub>2</sub> emission allowance prices each year through 2112 (100 years) and the cost of repairing the wellbore in a deep well located at

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<sup>12</sup> IEAGHG Risk Scenarios Database found online at: <http://www.ieaghg.org/index.php/?/20091223132/risk-scenarios-database.html>.

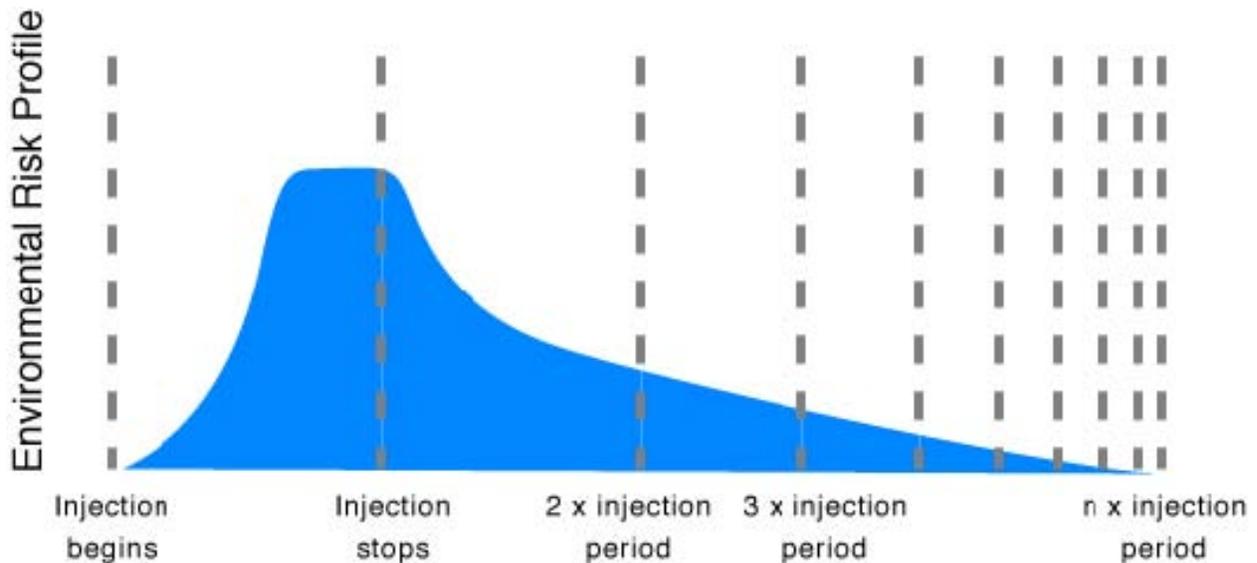
5,000 feet (1,524 meters). The project sponsors consulted among themselves and with experts to develop specific assumptions for these variables for use in testing the model.

IEc developed cost curves for each event type that reflect available information and the potential variability in the type and/or magnitudes of underlying impacts. For example, the type, number and cost of human health impacts arising from pipeline release will vary depending on the location of the release relative to population centers. The model utilized cost data from a variety of sources, including (but not limited to) court cases, insurance payments, and remediation costs to provide a reasonable range of event-specific costs of damages to human health and the environment.

**Step 4: Combine the Cost Relationships into an Integrated Model**

IEc combined the data and relationships developed in the previous steps into an integrated spreadsheet model that generates damage estimates based on a random sampling of the underlying probability distributions and cost curves across all potential events and over a 100-year period that includes 50 years of injection and 50 years of post-injection monitoring.

In the ideal situation, a scenario is expected to look something like the shaded area in Figure 2, which shows the expected risk of leakage of CO<sub>2</sub> from geologic storage over a project’s lifetime. It illustrates the expectation that at properly-sited, operated and closed CCS projects, the risk starts at zero, rises while early injection increases pressures in the storage formation, flattens during routine operation and then falls when injection ceases. The risk then further decreases over time to nearly zero as the injected CO<sub>2</sub> dissipates into the geologic formation and various geologic trapping mechanisms have more effect.



**Figure 2. Hypothetical Example of the Variation of Risk over Time for Geologic Storage of CO<sub>2</sub>.**

Source: Adapted from Sally Benson, Stanford University.

In reality, this is just one possible outcome. A project may face unforeseen site conditions, such as an undetected old well or fault; operator error; or some other factor could come into play. Mitigation may be prompt or it may be delayed. The population characteristics around the site may change over time. The output from a single scenario is of one possible outcome but, if it is run multiple times with different possible assumptions, the model will produce multiple outcomes drawing on many possible combinations of the underlying conditions. This random sampling of the range of possible outcomes serves as the basis for a statistical analysis of the likely outcomes.

### **Step 5: Use Probabilistic Modeling to Explore the Range of Possible Costs**

Monte Carlo simulation is a widely-used and well-accepted method for modeling uncertain financial outcomes. As discussed below, IEC constructed the model to use Monte Carlo simulation to generate, compile, and analyze an array of roughly 100,000 possible scenarios, a sample size that is large enough to generate confidence in the results. The model compiles the results from these scenario probability distributions of the cost of damages. These probability distributions illustrate the statistical range of possible outcomes from the modeled project.

### **Application to a Real World CCS Project**

Estimates of distributions of financial damages were made for a proposed CCS project in Jewett, Texas in the United States. This project was one of several proposed as part of the US Department of Energy's FutureGen initiative. FutureGen is a public-private partnership that intended to build and operate an integrated CCS project in the US.<sup>13</sup> Announced in 2003, the original concept (FutureGen 1.0) established a competition to encourage entities to submit proposals for specific projects located at specific sites. This process was shared with the public through publicly available documents posted on the FutureGen website. The original set of submissions was narrowed to a group of four sites, one of which was the Jewett, Texas project.

Each of the four selected projects submitted a detailed Environmental Impact Volume (EIV) in order to continue in the competition. The EIVs were developed through a peer-reviewed process and provided detailed technical risk assessments for these specific locations. The EIVs were preliminary assessments based mostly on available data rather than new site characterization work (i.e., new seismic surveys, test wells). It was understood that once a final site was selected, additional site characterization work would be undertaken for project finalization and design. (Such additional site characterization was not expected in the published Jewett risk assessment given the stage of the decision process.) Still, the publication of the four EIVs was a valuable resource in developing approaches for evaluating economic risk. IEC reviewed the four candidate sites and determined that they provided enough information to test the model and to develop insights from the results. The Jewett, Texas site was selected and the risk assessment in its EIV was used as the basis for the test.

The proposed Jewett project included a 275 Megawatt Integrated Gasification Combined Cycle (IGCC) power plant on a site of about 75 acres (30 hectares) located in a rural setting with a low population density. Given the nature of the specific IGCC process, the plant would capture CO<sub>2</sub> and trace amounts of hydrogen sulfide (H<sub>2</sub>S), a toxic gas that would not be present in most CCS projects. This mix would be transported through a 59-mile (95-kilometer) pipeline to another rural setting where up to three wells were planned for injection. The area around the injection wells was primarily used as ranchland and the project had acquired the right to use 1,550 acres (627 hectares) surrounding three potential injection wells. Figure 3 shows the layout of the Jewett project, including the capture plant, pipeline and injection sites for sequestration.

The site-specific characteristics were generally considered to provide a low-risk environment for a CCS demonstration in that the geologic formations included substantial reservoirs for injection and it appeared that there was a good and thick cap rock. Further it was located in a region that was sparsely populated with limited potential for biodiversity impacts.

The risk assessment for the Jewett site made quantitative estimates of the magnitude and probability of those risks deemed to have some potential for harm based on site characteristics and provided a qualitative discussion of those risks deemed not important at the site. This assessment was based primarily on information available at the time. Developing quantitative estimates for the remaining risks would have required additional advanced site characterization work. In order to apply the comprehensive model to the Jewett site, the study participants developed a "hybrid" case that included assumptions for the risks and/or variables which could not be quantified using data from the Jewett risk assessment.

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<sup>13</sup> For a concise description of FutureGen see the FutureGen Alliance website: <http://www.futuregenalliance.org/>.

What follows is a brief description of how the data were included in or addressed through each of the steps of the model.

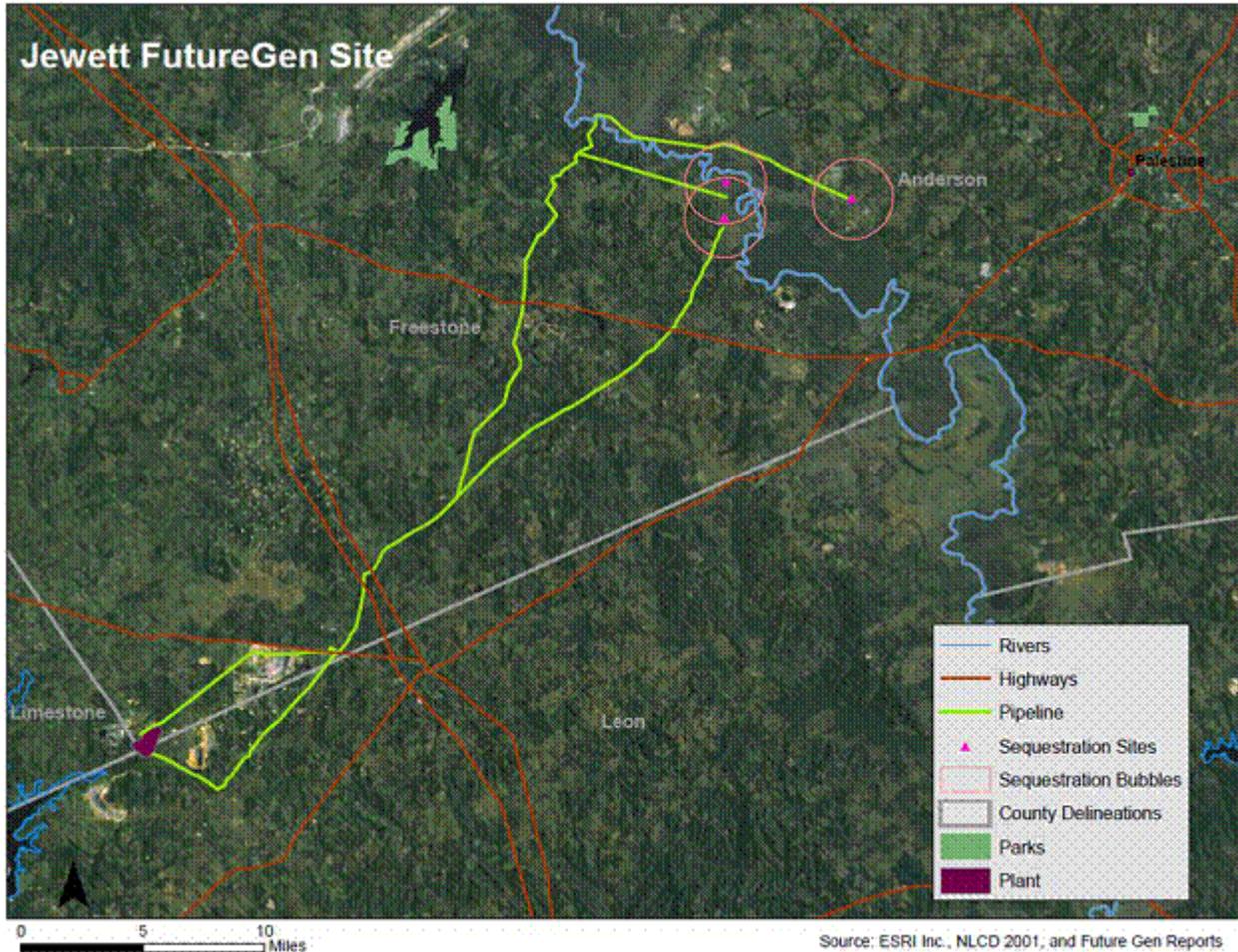


Figure 3. Overview of Jewett FutureGen Site

### Step 1. Selection of Relevant Risk Events

The risk assessment was reasonably thorough and evaluated several potential events and mechanisms at the Jewett site associated with capture, transport, and injection through which CO<sub>2</sub> or H<sub>2</sub>S could leak and was the primary source relied upon to select relevant events. The presence of H<sub>2</sub>S was due to the separation and capture technology choice proposed at Jewett and would not be present in many CCS projects. IEC expanded the damages model to include H<sub>2</sub>S consistent with risk assessment findings that releases of this substance at this site had the potential to cause human health and/or environmental impacts.

### Step 2. Characterize the Magnitude and Probability of Risk Events

For most of the identified events and mechanisms, the FutureGen risk assessment quantified the magnitude of potential releases and the probability of their occurrence based on site-specific information. Event probability estimates not included in the original EIV, such as yearly rates of pipeline accidents and failure of separation /compression equipment, were addressed through review of comparable, publicly-available data and discussion with industry experts. Event magnitude information was also missing for a few types of events (e.g., the amounts and durations of release of injected gas from the deep well to groundwater at the surface and from the deep well to the atmosphere.) The project sponsors consulted among themselves and with experts to develop specific assumptions for these variables for use in testing the model.

**Step 3. Evaluate the Potential Costs of Impacts**

IEc considered technical literature and publicly-available databases to tailor their cost curves to the Texas site. For example, they reviewed Texas case law and other databases to determine certain costs related to human health damages. Potential groundwater damages were dependent in part on the background mineral content of the rock formations in the region, which was not included in the risk assessment. In that case, the project sponsors consulted among themselves and with experts to develop an average mineral content variable for use in testing the model.

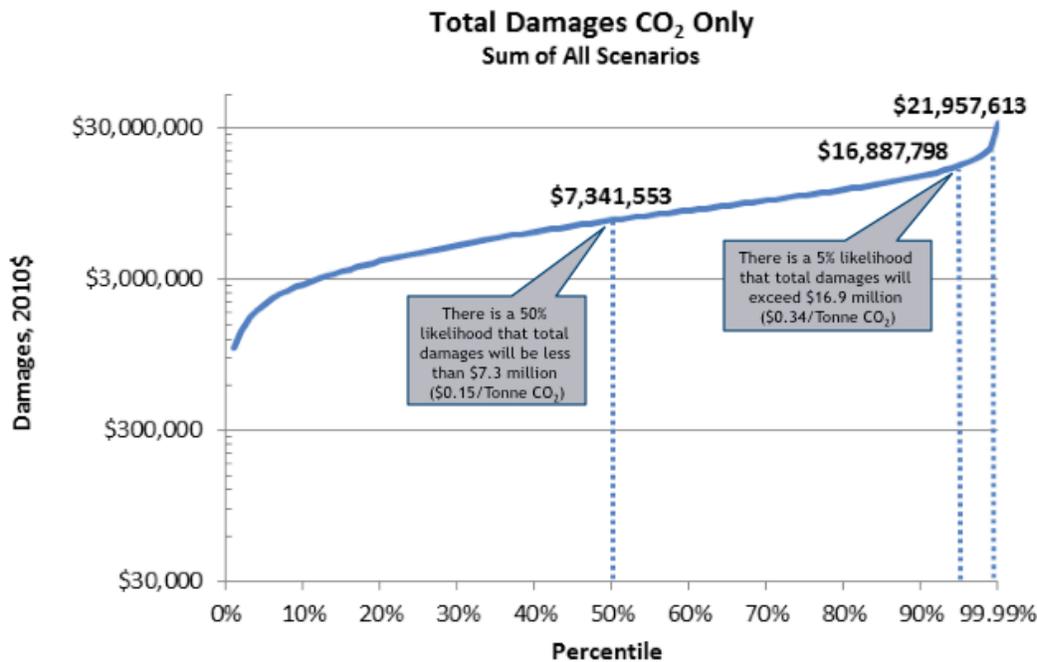
**Steps 4 and 5. Evaluate the Site Using Probabilistic Simulation**

IEc conducted 100,000 model runs for the Jewett project. This large number of samples was used to help ensure that the resulting distribution of the probability of financial damages appropriately captured the effects of even low probability events.

**Results**

The median value of damages at this site from the 100,000 model runs are estimated to be US\$7.3 million, as indicated in Figure 4. Total damages estimates for 95 percent of all model runs were below US\$16.9 million. These estimates translate into approximately US\$0.15 and US\$0.34 per tonne of the total of 50 million tonnes of CO<sub>2</sub> expected to be sequestered at the Jewett Site. These estimates value all potential adverse events over the 100 years and are expressed in 2010 dollars.

The distribution of the damages shown in Figure 4 is for CO<sub>2</sub> only since that would probably be similar to most CCS projects. The distribution values were about 10-15% higher when potential leakages of H<sub>2</sub>S were included. H<sub>2</sub>S releases are the primary driver of human health effects in this case. The model shows that more than 95 percent of the estimated damages at this site are due to potential releases from existing oil and gas wells at this site—risks that could be mitigated through well completion work or that would be avoided at projects that are not located in oil and gas production areas. Risks associated with other types of events—at the sequestration site, at the capture plant, or from the pipeline—are negligible or very low. This result serves as a preliminary estimate but some remaining uncertainty regarding carbon prices and impacts have not fully assessed at the site. Such uncertainty could be reduced through further site characterization work.



**Figure 4. Estimated Jewett Project Damage Distribution for CO<sub>2</sub> Capture, Transport and Storage.**

Source: Industrial Economics, Incorporated, “Valuation of Risks Arising from a Model, Commercial-scale CCS Project Site,” Cambridge, MA, June 2012.

## Conclusions

This study demonstrates that the financial risks associated with CCS projects can be quantified by standard analytical techniques. This challenges the widespread misperception that the costs associated with the risks of CCS cannot be quantified. It further shows how uncertainty can be explicitly taken into account.

This study demonstrates that well-sited and well-operated CCS projects can be expected to result in a relatively small potential financial risk for damages to human health and the environment compared to both the planned project costs and the benefits of such projects. Choice of the site is critical. Site characteristics—both the geologic factors that affect risk and the potential exposure of humans and the environment—are major determinants of risks. Although the results are based on a single early-stage project using generalized data, they give insight into the likely range of damage costs that can be expected at well-selected and operated projects.

Importantly, this flexible approach can be applied to projects at different stages of development. Early in project development, when detailed site-specific information is limited, general data from multiple sources can be used for site screening and selection. As site-specific, more-detailed and accurate data is gathered, this better data can be used to improve risk estimates, finalize site selection and design the project to minimize risks. As the project is implemented, the approach can be used to improve the safety of operations and avoid potential problems before they arise.

The application of the approach used in this study can help developers of CCS projects better site and design their projects to mitigate risk and confidently make investment decision. This information can be used by regulators and project developers to inform regulatory and permitting decisions and to establish regulatory timeframes and financial assurance mechanisms. The financial community can use this information to better evaluate project investments. Perhaps most importantly, this information can be shared with the public to build confidence in projects.

## **Appendix D Presentations**

### Session 2

George Guthrie  
Matt Gerstenberger  
Hallvard Høydalsvik  
Qi Li

### Session 3

Bill Spence, Shell  
Richard Esposito

### Session 4

Eric Redman

### Session 6

François Kalaydjian

## Geological Risks

### Discussion Leader

George Guthrie: US Dept. of Energy  
Chair, CSLF Task Force on Risk Assessment

### Australia

Matt Gerstenberger: CO<sub>2</sub>CRC

### Europe

Stefan Bachu: Alberta Innovates–Technology Futures

### Europe

Hallvard Høydaalsvik: Gassnova sf

### Developing Country

Li Xiaochun: Chinese Academy of Sciences



## Technical Group's Risk Assessment Task Force

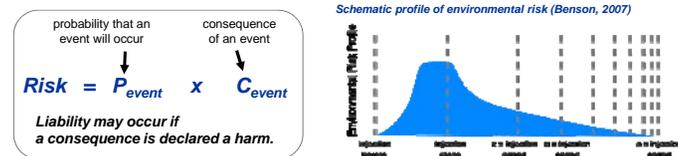
- **Initiated at London (Nov 2006)**
  - Charter: Examine risk-assessment standards, procedures, and research activities relevant to unique risks associated with the injection and long-term storage of CO<sub>2</sub>
    - Risks associated with CO<sub>2</sub> near-term (injection) processes (including fracturing, fault re-activation, induced seismicity)
    - Risk associated with long-term processes related to impacts of CO<sub>2</sub> storage (including
- **Phase I report complete (fall 2009) (CSLF-T-2009-04)**
  - Multiple potential impacts considered
  - Several recommendations from RATF, including: *The link between risk assessment and liability should be recognized and considered*
- **Phase II initiated fall 2010**
  - Activities related to risk-liability include overviews on:
    - Enhanced Oil Recovery
    - Project phases (injection, post-closure, long-term)



## Potential Impacts Considered by the Task Force

- impingement on pore space not covered under deed or agreement
- impingement on other subsurface resources
- change in local subsurface stress fields and geomechanical properties
- impact on the groundwater and/or surface water
- elevated soil-gas CO<sub>2</sub> in terrestrial ecosystems
- accumulation in poorly ventilated spaces or in low lying areas subject to poor atmospheric circulation
- CO<sub>2</sub> or other displaced gases (such as methane) return to the atmosphere

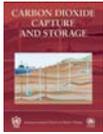
Risk relates to the probability that an event will occur as well as the consequence of that event; risk can vary over time.



Geological factors tie to the probability that an event will occur,  $P_{\text{event}}$

Time evolution of risk may imply various regimes or phases of a project (e.g., injection phase, post-injection phase, long-term stewardship phase).

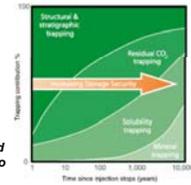
**Broad knowledge base provides foundation for confidence in long-term geologic storage security.**



IPCC (2005)

"Observations from engineered and natural analogues as well as models suggest that the fraction retained in appropriately selected and managed geological reservoirs is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1,000 years."

Schematic evolution of trapping mechanisms over time (IPCC, 2005)



**What do we know?**

**Multiple trapping mechanisms reduce CO<sub>2</sub> mobility over time**

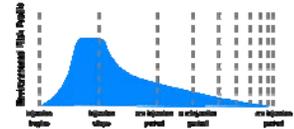
- structural/stratigraphic; residual; solubility; mineralization; sorption

**Risk profiles should decline over time**

**Broad experience base for effective site-characterization & operational strategies**

- Decades of successful operational experience (e.g., EOR, gas storage, ...)
- Early successes with field demos (e.g., Sleipner, In Salah, Weyburn, Regional Carbon Sequestration Partnerships)

Schematic profile of environmental risk (Benson, 2007)



**Several efforts are developing the quantitative basis for geologic storage security, including two in the US-DOE Program.**



**Site-Specific Assessments**

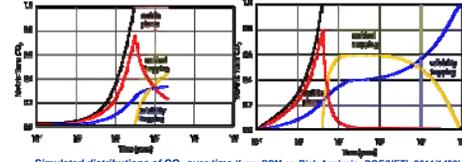
**Broadly Applicable Tools & Trends**

**nrp**  
National Risk Assessment Partnership

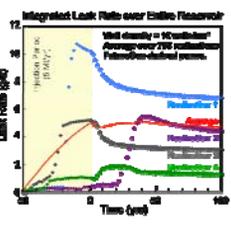
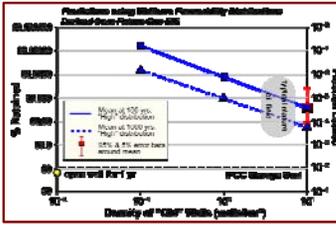
**NETL-RUA**  
National Energy Technology Laboratory - Regional User Agency

**Los Alamos**  
National Laboratory

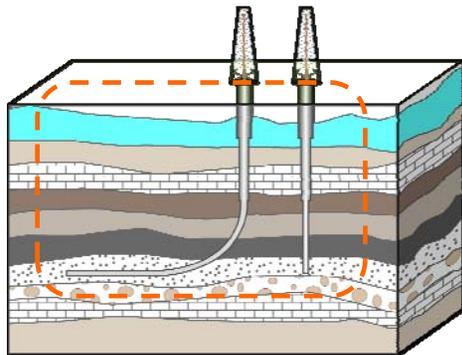
**Pacific Northwest**  
National Laboratory



Simulated distributions of CO<sub>2</sub> over time (from BPM on Risk Analysis; DOE/NETL-2011/1459)



**Predicting and assessing risks requires a consideration of the entire geological system, from reservoir to receptor.**



## Uncertainties in CCS Risk Assessment



**Matt Gerstenberger**  
*Senior Risk Analyst*  
GNS Science &  
Cooperative Research Centre  
for Greenhouse Gas  
Technologies (CO2CRC)

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CO2CRC

## Australia Risk Assessment

- Geodisc, Otway, Zorogen, Gorgon, Flagships (Carbonnet, SW Hub)
  - Heavy use of both RISQUE and Risk Registers
  - Qualitative probabilistic risk assessments
  - Strong interaction between operators and regulators
  - Operator advice on what is required for safe storage
  - Carbonnet: actively looking for existing methods

## Risk Assessment

- P from Probability X Consequences
- Focus on P
- P ultimately boils down to
  - What do we know?
  - How well we know it?
- Accurately understanding and reflecting the uncertainty in the risk is critical
- How do we estimate uncertainties & how good are the estimates?
- i.e., How could is the information we provide and how do we assess that.

## Uncertainties

- Geological storage risk assessment is heavily dependent on reservoir simulation, however concepts apply across all disciplines
- Many different uncertainties and ways to describe them, two broad categories:
  - Aleatory – random and irreducible
  - Epistemic – ultimately reducible
- Maybe easier in CCS risk context to describe with:
  - Static geological model
  - Other parameter uncertainty (effective porosity, relative perm, etc)
  - Model uncertainty – basic set up of dynamic model (grid spacing, physical eqs, geochemical eqs)

## Addressing the Uncertainty

Two main ways uncertainty is estimated and incorporated into CCS risk assessment

1. Simulations (Primary emphasis in CCS):
  1. Probability distributions on parameters, Monte Carlo simulations, use of multiple static models, etc
2. Expert Elicitation:
  1. Key to a full exploration of the uncertainty
  2. We know the model predictions are not correct
    1. Structured expert elicitation can help to better estimate and incorporate that uncertainty
  3. Final result is only as good as the EE process used
  4. EU Guidelines on structured EE, etc.
    1. Structured elicitation, workshops, etc
    2. Expert selection
    3. Expert Bias (last two challenging to get around in industry application)

## Interdependence of risks & the effect of mitigation on risk

- Risks are not independent of one another (e.g., induced seismicity and leakage/migration through a fault)
- Mitigation measures may have effect on risk in other parts of the system (e.g., additional injection wells: reservoir behaviour, financial risk, etc)
- Economics: capacity/volume stored is not independent of economics (i.e., carbon price) & hence risk

## Key Uncertainties

- Long term behaviour
  - is it truly a steady decrease? Estimating change with time is key
- Volume scaling behaviour?
- Reservoir modelling: understanding if/how the uncertainties change with time (testing models beyond history matching)
- Induced seismicity

## Liabilities related to saline aquifer storage of CO<sub>2</sub>

AN EXAMPLE FROM THE NORTH SEA AND THE JOHANSEN FORMATION



Eirik Harding Hansen, Asset Manager, Gassnova SF  
CSLF Workshop on Risk and Liability, Paris 2012

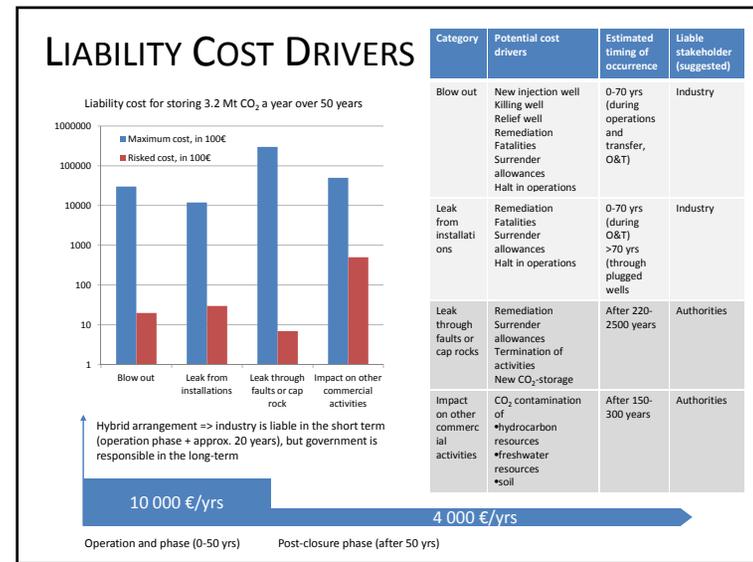
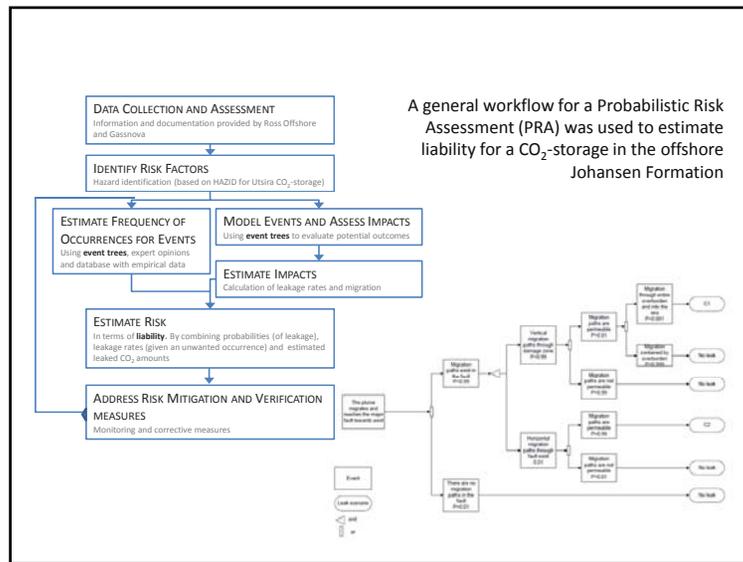
8/11/2012

### Case study: the Johansen Formation

Key data	
Location	The northern North Sea (approx. 70-80 km offshore)
Depth	3000m
Storage formation	Johansen Formation
Storage formation thickness	80-180m
Primary seal	Lower Jurassic Dunlin Group
Secondary seal	The Brent and Viking Groups + shallower layers of Cretaceous and Tertiary age (>1700m)
Injection volume	3.2 Mt/yr for 50 yrs
Storage capacity	>> 160 Mt
Leakage risk	0.0101% of the injected CO <sub>2</sub>



Outline (in black) of the storage complex and licenses (squares) in the area



Public Material

## Recommended risk assessment method related to CO<sub>2</sub> geological storage in China

**Qi LI and Xiaochun LI**  
 IRSM, The Chinese Academy of Sciences  
 Wuhan, China

*WORKSHOP ON RISK AND LIABILITY OF CO<sub>2</sub> GEOLOGIC STORAGE*  
 Sponsored by CSLE, GCCSI and IEA  
 9 rue de la Fédération  
 15th Arrondissement, Paris, France  
 10 and 11 July 2012

中国科学院武汉岩土力学研究所  
 Institute of Rock and Soil Mechanics, Chinese Academy of Sciences

## Outline

1. Current status
2. Lessons and experience learned
3. Recommended methodology
4. Question and gap

中国科学院武汉岩土力学研究所  
 Institute of Rock and Soil Mechanics, Chinese Academy of Sciences

## 1. Current status

CCS projects in Asia (till 2011)

CO<sub>2</sub>-EOR in Jilin oilfield

CO<sub>2</sub>-EOR in Dongying Oilfield

Shenhua CCS (storage in deep saline aquifer)

中国科学院武汉岩土力学研究所  
 Institute of Rock and Soil Mechanics, Chinese Academy of Sciences

## 1. Current status

Projects related

- CO<sub>2</sub>-EOR in Jilin oilfield  
*HSE assessment done*
- Shenhua CGS in saline aquifer  
*Study from EPA's, and other regulations*
- CO<sub>2</sub>-EOR in Dongying Oilfield  
*Towards fully understand and assess*

Preliminary

Towards full assessment

中国科学院武汉岩土力学研究所  
 Institute of Rock and Soil Mechanics, Chinese Academy of Sciences



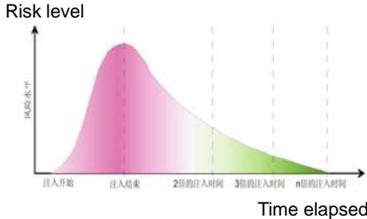
2. Lessons and experience learned

AGI DB

级分类 基本信息 (Basic Information)							
二级分类	项目编号	项目名称	开始时间	纬度	经度	国别	各省市
数据信息	#	Project	start up time	Latitude	longitude	Country	County
数据库英文							具体到县市的级别
海洋	1242	Normandville	1997/9/29	55.002	-117.486	Canada	Peace River Arch
	3864	Mysof	2018/11/4	51.4117	-118.8007	Canada	Peace River Arch
	1409	Dumrean	1995/1/1	55.999	-110.529	Canada	Peace River Arch
	2119	Peace Dugue	1994/2/19	51.9617	-114.471	Canada	Peace River Arch
	3750	Wetlow	2012/5/20	55.528	-119.57	Canada	Peace River Arch
	2982	Mulligan	1993/12/4	54.1	-119.796	Canada	Peace River Arch
	312	Grindonair-Halfway	1995/12/21	55.818	-119.201	Canada	Peace River Arch
	320	Grindonair-Folley	1995/6/8	55.878	-119.281	Canada	Peace River Arch
	1306	Edmonton	2003/11/6	55.76	-117.706	Canada	Peace River Arch
	997	Mirage	1995/10/2	55.96	-119.07	Canada	Peace River Arch
	4512	Parkland	2011/2/22	56.059	-120.321	Canada	Peace River Arch
	3340	Acheson	1983/6/29	53.547	-113.735	Canada	Peace River Arch
	2001	Golden Spike - Beaverhill Lake	1989/4/23	53.43	-113.800	Canada	Peace River Arch
	2409	Redwater	1987/11/17	51.549	-113.025	Canada	Peace River Arch

3. Recommended methodology

- Space dimension to be covered
- Time dimension to be assessed

3. Recommended methodology

Matrix for CO<sub>2</sub> geological storage

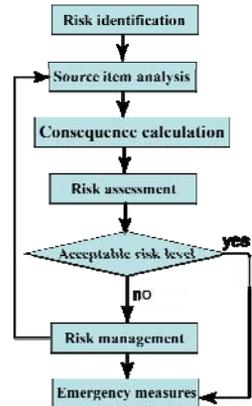
Indicators
Local EHS risks
Noise, light and odour nuisance
Soil pollution
Ecology
Landscape
Waste products
Energy required
Biodiversity
Gaseous emissions
Groundwater and surface water contamination/disruption

What should be included?

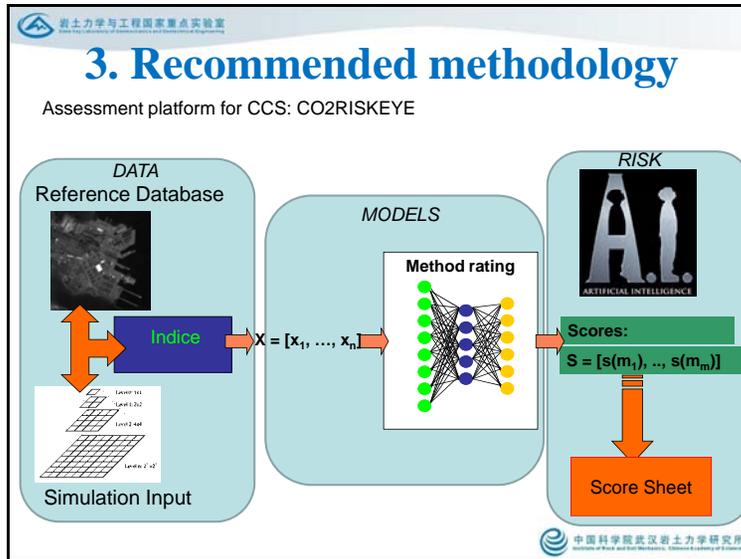
3. Recommended methodology

Method and Flow

- Modified Oldenburg's HSE Method
- AIST GSJ Method
- AHP Method
- Dynamic Programming Approach
- .....



Methods and Criteria should be tailored for different types of geological storage.



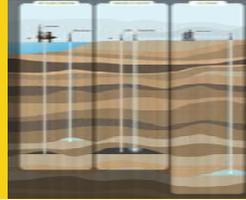
- 岩石力学与工程国家重点实验室  
State Key Laboratory of Geomechanics and Engineering of Geotechnical Engineering
- ### 4. Question and gap
- The short- and long-term effect of  $\text{spCO}_2$  in influencing geological structure are not well understood.
  - Assessment need an indicator system and more theory research to support the analysis, but they are very lacked.
  - Current methods do not exist to implement assessments upon which risk assessments depend.
- 中国科学院武汉岩土力学研究所  
Institute of Rock and Soil Mechanics, Chinese Academy of Sciences





## CARBON CAPTURE AND STORAGE RISK ASSESSMENT AND MITIGATION

CSLF Workshop  
Paris, France  
July 10-11, 2012

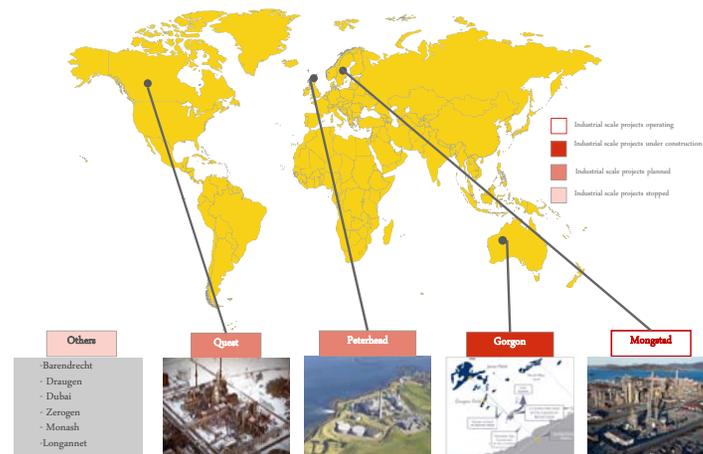


Shell Exploration and Production International  
Bill Spence – Manager Strategic Issues

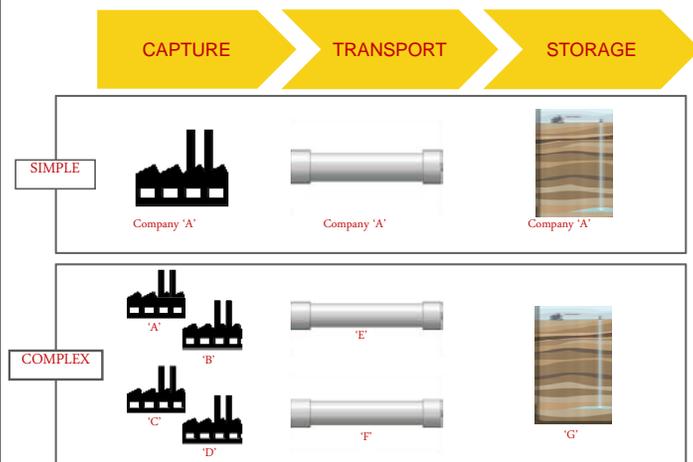
## DISCLAIMER STATEMENT

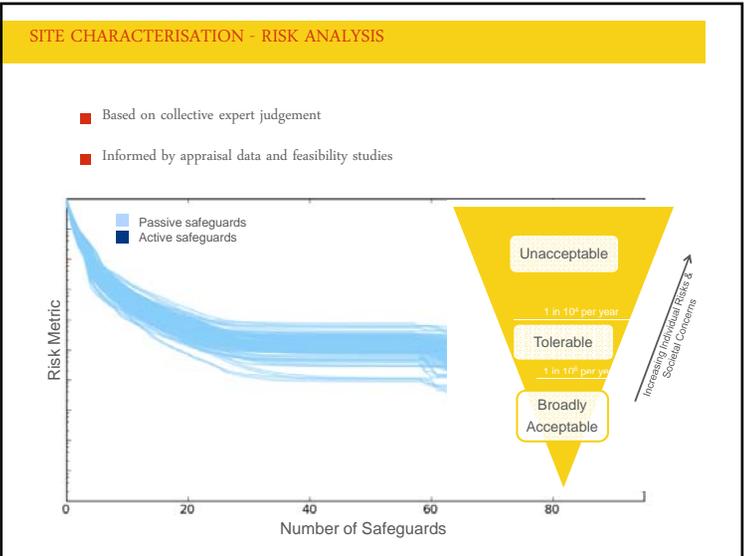
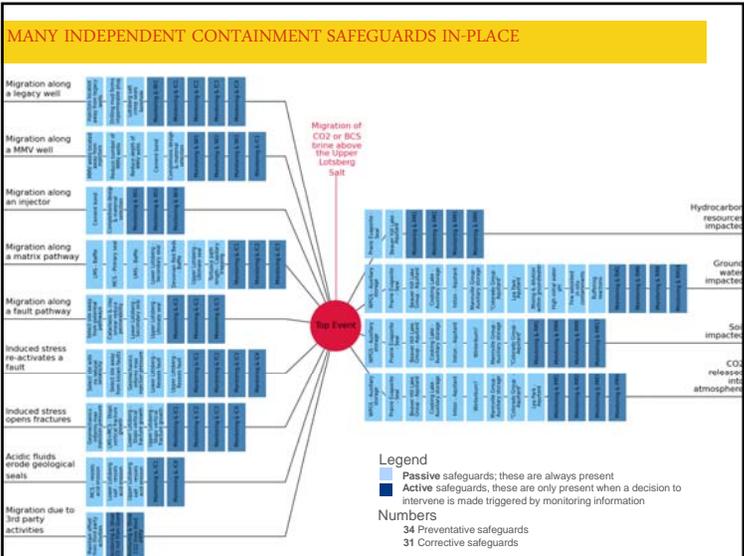
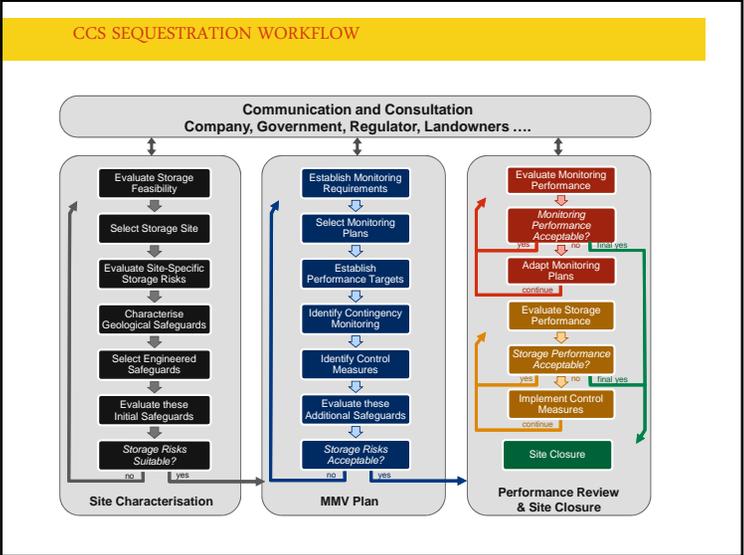
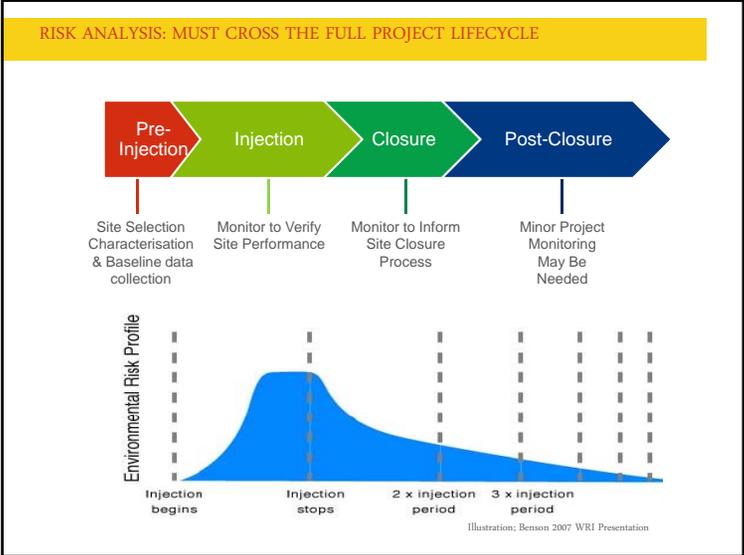
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## SHELL EXPERIENCE BASE – LARGE SCALE CCS PROJECTS



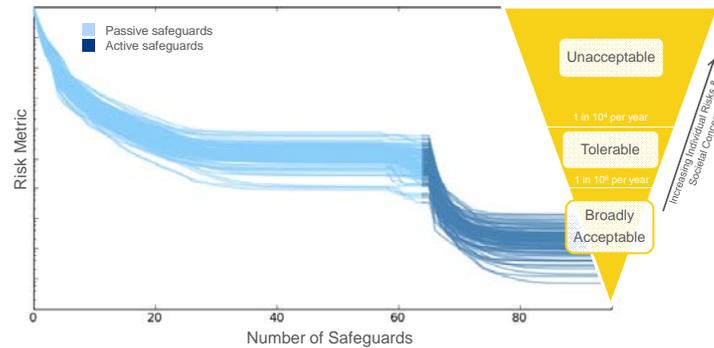
## GOING FORWARD – COMPLEXITY WILL INCREASE





## MMV CONTRIBUTES TO RISK ACCEPTANCE

- Based on collective expert judgement
- Informed by appraisal data and feasibility studies



## CCS COMMERCIAL VIABILITY SOLUTION SPACE

- Commercial operators can not bear **unlimited** liabilities
  - EU legislation proposes that operator will have to compensate for any leakage by providing emissions allowances, this could result in unlimited liabilities for operators.
  - There are uncertainties such as available technology/costs long term, scope of financial contribution for MMV at handover to government etc.
    - ⇒ Solutions include capping the emissions allowance repurchase price at level agreed pre injection and agreement on MMV costs
- Commercial Operators can not bear **indefinite** liabilities :
  - Recent legislation in some countries/ areas of the world have planned a handover of storage liabilities to local authorities at some points, however:
    - ⇒ Transfer needs to be effective / clear cut (cf. EU ambiguities).
    - ⇒ Criteria for transfer need to be pre-agreed & achievable ("stable condition").

## SUMMARY

- Risk & Uncertainty needs to be addressed at every phase of the project
- Different stakeholders will focus on different risk elements
  - Landowners – HSSE, Containment
  - Government, Regulator – HSSE, Containment, Capacity and long term liability
  - Proponent - HSSE, Containment, Capacity, Injectivity, Financial, Long Term liability
- An Industrial Scale Integrated project needs to address them all
  - Site Selection – Reduction/elimination/isolation from risk
  - Site Characterisation – Reduction in uncertainty and remaining risk
  - MMV – Risk monitoring and mitigation
  - Site Closure – Risk Transfer



## EGU-CCS; risk comparison

- Electrical utilities are sophisticated in the identification, acceptance, and management of risk. We are both “risk-curious” and “risk-analytic”.  
*Long-term risk presents more uncertainty.*
- Utilities are accountable to a wide range of stakeholders such as the PSC, shareholders, customers, and the general public.  
*Utilities have significant exposure and reporting requirements related to investments decisions.*
- Many uncertainties related to EGU-CCS, while not the same as “business as usual” activities can be compared; therefore more experience with CCS will make industry more comfortable with it.
  - *CO<sub>2</sub> capture can be compared to environmental controls such as FGD, SCR, bag-houses*
  - *CO<sub>2</sub> transportation can be compared to e-transmission & distribution as well as natural gas pipelines*
  - *CO<sub>2</sub> storage can be compared to wastewater injection*
  - *Long-term liability of stored CO<sub>2</sub> can be compared to storage of nuclear fuel rods, ash & gypsum, and hydroelectric plants*

## EGU-CCS; other important risks

- The costs associated with EGU-CCS represent a greater obstacle to commercial deployment than the environmental risks.  
*CCS is hampered by the level of regulation with associated cost uncertainty which misalign CO<sub>2</sub> with the level of protection of air toxins.*
- There is uncertainty related to future operational flexibility in bypass.  
*Is the tail wagging the dog with geologic sequestration?  
CCS is hampered by concerns with the requirement to reliably produce power.*
- Risk associated with off-site storage will require new business models.  
*CCS is hampered by vertical integration with contractual relationships and complexity of partners with environmental and permit compliance implications.*
- Risk always exists with immature regulatory and permitting frameworks.  
*Uncertainty exists with the integration of project development, operations, and finance.*

## Risks associated with false risk perception still exist

E. Downs Green, Gulfport Mississippi quoted in the Sun Herald Newspaper

*“What if the pumping of all this exhaust gas deep underground causes a huge explosion, releasing a noxious toxic cloud of coal gas that gets ignited above ground, barbecuing the surrounding area?”*

## CCS Liability in the United States:

### Examples of Federalism at its Best and Worst

Eric Redman, President  
Summit Power Group, LLC & Summit Carbon Capture, LLC

Carbon Sequestration Leadership Forum  
Workshop on Risk & Liability  
Paris • July 10, 2012

## A Cautionary Note on Limitations of the Format

“In August, the Columbia Accident Investigation Board at NASA released . . . its report on why the space shuttle crashed. As expected, the ship's foam insulation was the main cause . . . But the board also fingered another unusual culprit: PowerPoint, Microsoft's well-known 'slideware' program.

“NASA, the board argued, had become too reliant on presenting complex information via PowerPoint . . . 'It is easy to understand how a senior manager might read this PowerPoint slide and not realize that it addresses a life-threatening situation,' the board sternly noted.”

*From “PowerPoint Makes You Dumb”*

*By Clive Thompson*

*New York Times: December 14, 2003*

## Preliminary Matters, before turning to Liability Issues:

Some (entirely personal) observations on risks

## Questions posed regarding CCUS safety

### • Operational Risks

- Induced seismicity
- Corrosion and failure of well
- Pipeline transport risk

### • Long-term risks

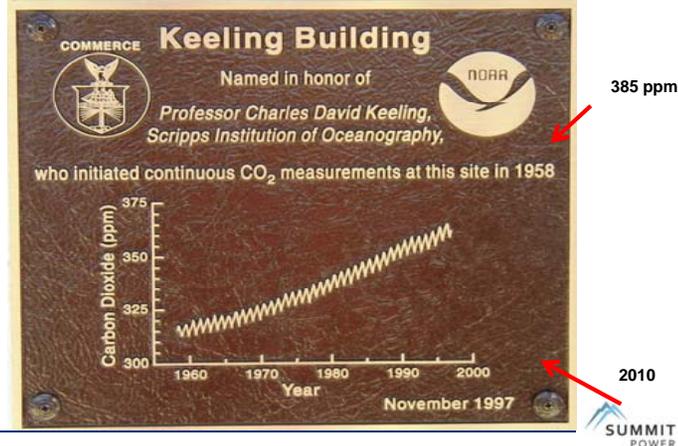
- Groundwater contamination
- Leakage (wells or natural pathways)

### • Health and safety risks



*Slide courtesy of Lawrence Livermore National Laboratory*

Rising CO<sub>2</sub> concentration in the atmosphere is not a risk: it is a fact.



CO<sub>2</sub> escaping geological sequestration is a risk, but how large? How hazardous? How significant (and manageable) compared with the Keeling Curve's risks?



Video (42 seconds) of Crystal Geysir in Utah – erupting 1 to 3 times per day, venting about 40 tons per day of CO<sub>2</sub> from a natural aquifer. Drilled by accident in 1936 and not capped.

“A good analog for how CO<sub>2</sub> might leak from a bad well [until capped].”

– Dr. Julio Friedmann, Lawrence Livermore National Laboratory

(Put cursor on photo to play video)

### Preliminary Observations:

“Carbon sequestration isn’t rocket science – it’s rock science.” Dr. Julio Friedmann

Mother Nature has sequestered gigatons of carbon for eons with almost no escapes

Geological injection of CO<sub>2</sub> is not *really* a major potential hazard to human health

- CO<sub>2</sub> itself is not inherently hazardous (unless you & it are in a hole together)
- Risk of leakage (or earthquakes) from properly selected sites is small
- Monitoring techniques are available to detect any leakage, should it occur
- Mitigation techniques are available to halt any leakage, should they be needed
- Consider: Natural gas pipeline hazards & experience, and natural gas storage

CO<sub>2</sub>/EOR is secure & better understood (with lower net costs) than non-EOR CCS

- Oil reservoirs are natural traps; have survived eons of seismicity without leaks
- CO<sub>2</sub>/EOR doesn’t over-pressurize reservoirs – that would be counter-productive
- In No. America, CO<sub>2</sub>/EOR is a bridge to non-EOR CCS – a big, wide, long bridge
- Elsewhere, non-EOR CCS is seen as a (potential) bridge to CO<sub>2</sub>/EOR



CCS Liability Regime in the United States: “Crazy Quilt Federalism”

## Overview

For nuclear power, since 1957 the Price-Anderson Act has governed liability:

- "The main purpose . . . is to partially indemnify the nuclear industry against liability claims . . . while still ensuring compensation coverage for the general public.
- "The Act establishes a no fault insurance-type system in which the first approximately \$12.6 billion (as of 2011) is industry-funded. Any claims above the \$12.6 billion would be covered . . . by the federal government.
- "[I]t was considered necessary as an incentive for the private production of nuclear power — this was because electric utilities viewed the available [commercial insurance] liability coverage (only \$60 million) as inadequate." -- Wikipedia

Attempts to enact an analogous Federal law for CCS have gone nowhere

As a result, CCS legal liabilities are generally determined by state laws:

- Few states have enacted CCS liability (or other CCS) statutes, and these don't match
- Some states (e.g., Texas) have clear laws for CO<sub>2</sub>/EOR but not necessarily for non-EOR CCS
- Federal government (EPA) has begun to regulate some (not all) CO<sub>2</sub> injections



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## CO<sub>2</sub> for Enhanced Oil Recovery – Texas example re: liabilities

More than 90% of all oil recovered with CO<sub>2</sub> has been recovered in Texas: 40-year history of injection, currently about 100 million tons total per year

State regulatory approval is required for EOR injections (both H<sub>2</sub>O & CO<sub>2</sub>)

Once approved, injections can proceed with no duty to remove injectant:

- This applies to both water and carbon dioxide, if injected to extract minerals
- Right to inject without duty to remove later: This creates an effective right of storage

In addition, top Texas court has effectively eliminated actions for trespass

- So long as injection was state-approved for mineral extraction, no migration into adjoining areas is actionable under the "reverse right of capture" doctrine

"Who owns the pore space?" is thus largely moot for CO<sub>2</sub>/EOR in Texas, but:

- Some cautious folks are nonetheless optioning storage rights from surface owners
- Texas does have a statutory sequestration standard (99% for at least 1,000 years)
- Texas gives tax breaks for capture & EOR use of CO<sub>2</sub> from power plants (HB 469)
- Texas requires monitoring/verification/accounting as a condition of these tax breaks
- Liability for escapes? Presumably with operator, but unlikely in EOR context



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## Commercial CO<sub>2</sub> Storage Projects (non-EOR), State by State\*

- In the U.S., there is a trend toward states (1) clarifying that pore space is owned by surface owners, and (2) providing for unitizing or pooling rights at a storage site
  - This incentivizes surface owners; C12 Energy & others typically agree to pay owners a small upfront fee plus a royalty during injection operations
  - This engenders support; C12 Energy has communities seeking to host commercial CO<sub>2</sub> storage projects
  - Outside the U.S., surface owners often don't own the subsurface. They may see only risk of CO<sub>2</sub> storage. Where surface owners can own the pore space, incentives may change the viewpoint of the surface owners.
- [Information on this & following slides courtesy of C12 Energy -- special thanks to Daniel Enderton](#)



## Examples of Community Support Where Landowners Can Earn Revenue

**Underground Carbon Storage**  
**Ideal site located in Fayette County**  
*Effingham Daily News, October 18, 2010*

**County Board Members Unanimous in Support of Carbon Storage Site Application**  
*November 23, 2010*

**Hope, Optimism Abound in Fayette County's Bid for Carbon Storage Site**

**"If we can bring in 75 new or better paying jobs, why don't we give this a shot those of us who are fortunate enough to own land?"**  
-Dean Buzzard, Landowner  
*Effingham Daily News, January 14, 2011*

**"The city and county need this."**  
-Steven Knebel, Fayette County Board Chairman  
*Effingham Daily News, November 18, 2010*

**"It's an important project for the economy."**  
-Ricky Gottman, Mayor of Vandalia  
*Herald Review, January 13, 2011*

## Risk and Liability in State CCS Statutory Schemes

- Consensus is building on state CO<sub>2</sub> storage liability regimes. With some exceptions, the storage operator will bear liability during (1) the operational phase of a project, and (2) a post-closure monitoring period, until the CO<sub>2</sub> plume is deemed to have become “stable.”
- Commercial insurance policies are available to cover operational liability risks; these risks (while somewhat new) are often analogous to existing risk profiles and may be quantified through well-understood means.
- States with statutory schemes have proven willing to assume liability after post-closure monitoring period, and/or create agencies/entities to do so.
- Site geology is critical to minimizing risks; it will affect ability to procure cost-effective insurance and demonstrate non-endangerment following a period of post-closure monitoring.



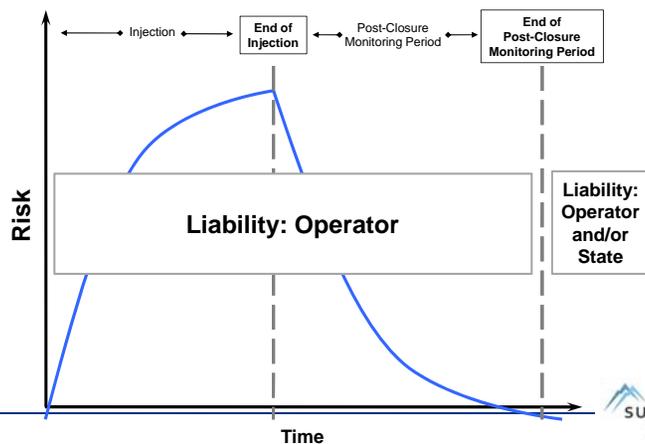
State	Pore Space Ownership	Aggregation	Long-Term Liability*
Kentucky	Surface Owner	Unitization (51%)	Public Entity (after 10+ years)
Louisiana	Surface Owner	Eminent Domain (75%)	Public Entity (after 10+ years)
Mississippi	Surface Owner	Unitization (Majority Interest)	Not the State
Montana	Surface Owner	Unitization (60%)	Public Entity (after 25+ years)
North Dakota	Surface Owner	Unitization (60%)	Public Entity (after 10+ years)
Wyoming	Surface Owner	Unitization (80%, petition to 75%)	Not the State

Note: For CO<sub>2</sub>-EOR, many states have unitization, with liability remaining with operator

\* State assumptions of liability after a period of post-injection monitoring typically based on a performance standard wherein plume must be “stable” before transfer

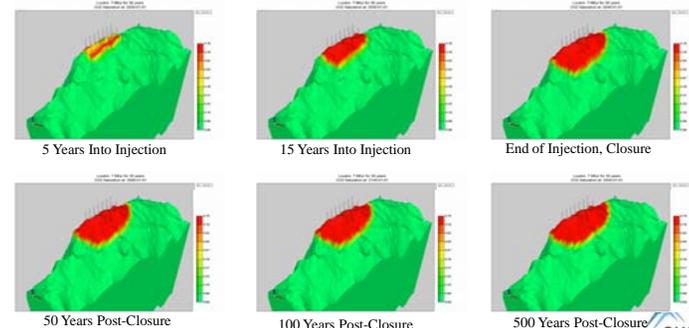


## CO<sub>2</sub> Storage Subsurface Project Risk Profile



## Geology Matters – An Example from C12 Energy

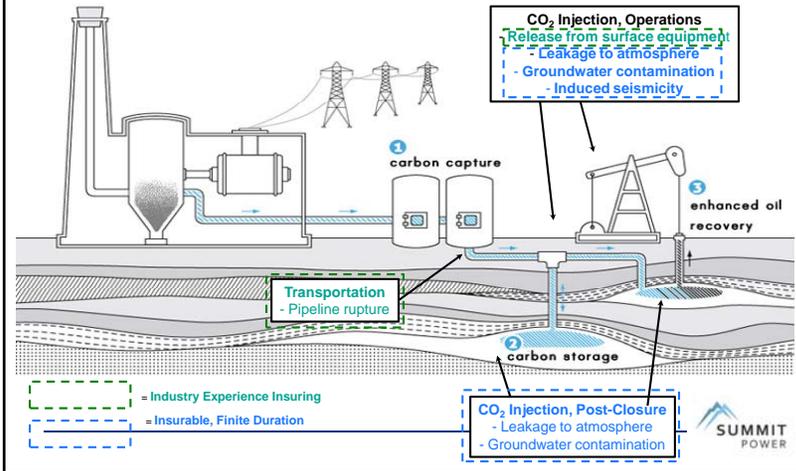
Leakage from reservoir to the atmosphere or groundwater contamination arises from CO<sub>2</sub> migrating vertically through wellbores or natural faults/fractures. Well chosen sites constrain CO<sub>2</sub> so that it doesn't migrate beyond project boundary and encounter leakage pathways that weren't fixed at the outset.



7 Mt/yr CO<sub>2</sub> Injection for 30 Years at the Loudon Anticline (Fayette County, IL)



## Classification of Key CO<sub>2</sub> Storage Risk and Liabilities



Risk Phase	Risk Category	Potential Adverse Event	Insurance Available	Geology Critical	State Assumption of Liability
Operations	Transportation	Pipeline Rupture	✓	✗	✗
Operations	Sequestration	Leakage	✓	✓	✗
Operations	Sequestration	Groundwater Contamination	✓	✓	✗
Operations	Sequestration	Induced Seismicity	✓	✓	✗
Long-Term	Post Closure	Leakage	[✗]*	✓	[✓]**
Long-Term	Post Closure	Groundwater Contamination	[✗]*	✓	[✓]**

\* Insurance available following end-of-injection in finite increments; trusts, escrows also possible  
 \*\* Several states with comprehensive CO<sub>2</sub> storage rules have some assumption of liability after a period of post-injection monitoring when plume is "stable"



## Liability Damages: The Industrial Economics Study

- Industry, government & environmental groups sponsored Industrial Economics, an expert in natural resource damage assessments, to estimate potential human health and ecological damages from well-selected & managed CO<sub>2</sub> storage project
- In 2012, IEc modeled a realistic project based on a site from the FutureGen process. The project was assumed to inject 50 million metric tons of CO<sub>2</sub> over 50 years and to have a 50 year post-injection period (for a 100-year analysis period).
- IEc estimated expected total damages arising from such a site to be \$7.3 million (50<sup>th</sup> percentile) and \$16.9 million (95<sup>th</sup> percentile).
- Equates to \$0.15 (50<sup>th</sup> percentile) and \$0.34 (95<sup>th</sup> percentile) per metric ton of CO<sub>2</sub>.
- Estimates include human health and ecological damages from all credible potential adverse events, such as pipeline ruptures & subsurface leakage, over 100 years.

Total damages estimate at 95<sup>th</sup> percentile is far lower than limits commercially available for pollution legal liability insurance policies for CO<sub>2</sub> storage projects.

Reference: Industrial Economics, Inc. "Valuation of Potential Risks Arising from a Model, Commercial-Scale CCS Project Site." June 2012.



## Pollution Legal Liability Insurance for CO<sub>2</sub> Storage

- CO<sub>2</sub> storage operators buy Pollution Legal Liability (PLL) insurance in addition to the standard liability insurance procured by most industrial businesses.
- PLL policies provide coverage for clean-up & remediation, third party bodily injury and property damage liabilities, and defense costs for covered conditions.
- Coverage includes contamination of underground source of drinking water (USDW); surface failure (e.g. pipeline leak); or subsurface failure (e.g. upward leakage or other subsurface release).
- Between five and ten PLL policies for CO<sub>2</sub> storage sites have been placed, and several more are pending, in the United States.
- ~10 insurers are currently willing to provide PLL policies for CO<sub>2</sub> sites, either as lead primary insurer or as excess carrier. A.M. Best ratings of this group of insurers range from A- (Excellent) to A++ (Superior).
- Each of the ~10 insurance carriers offers capacity of \$10 million to \$50 million.
- Total limits on policies placed in U.S. have ranged from \$15MM to \$200MM.
- As the market for these policies has developed over the past several years, insurance capacity has increased and premiums have come down.



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\* Generous contributors to, but not responsible for, this presentation; excellent contacts for those who would like to explore these issues more fully



## CSLF Workshop on Risk and Liability of Geological Storage July 10-11, 2012, Paris

### Session 6. How Safe is Safe Enough ? (cont'd)

#### Discussion leaders

Barry Worthington, USEA  
Francois Kalaydjian, IFPEN



## Questions

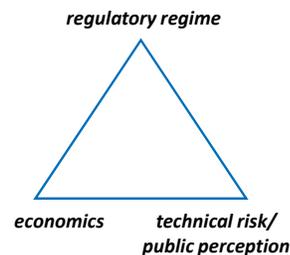
- What will make investors comfortable ?
- What geosciences information can create that comfort ?
  - What concepts and approaches for risk communication can be used ?
  - How can geosciences participate in effective communications ?
  - Are there relevant examples of effective or ineffective communications for geologic storage or from other fields ?



## What will make investors comfortable ?

### Safe enough ...

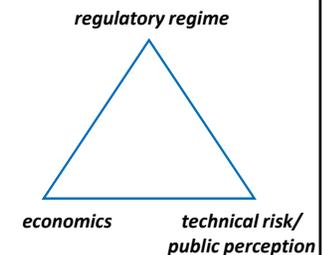
- for securing an attractive ROI (business case, value of CO<sub>2</sub>)
  - from 1 to 20 €/tCO<sub>2</sub>, CAPEX, geological uncertainty
- for allowing a transparent liability transfer from the operating companies to the public authorities (well stated regulatory framework)
- for minimizing technical risks and gaining public support



## What geosciences information can create that comfort ?

### ■ Issues

- improving performance
  - capacity, containment, injectivity, plume expansion, economics
- permits
  - characterization, injection, closure, post-closure
- derisking the storage
  - monitoring and surveillance, well and cap-rock integrity



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## What geosciences information can create that comfort ?

- **Safe and permanent storage** – To demonstrate that after 20-30 years of monitoring there won't be any evidence of a possible leakage.
- How to assess the long term behavior of a CO2 storage ?
  - Monitoring / surveillance surveys
  - Use of gauges (surface, downhole)
  - use of a numerical simulator
    - observations vs simulations
- **Acceptable leakage rate**
  - Data acquisition – level of accuracy
  - Numerical simulations, prediction

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## What concepts and approaches for risk communication can be used ?

- Zero risk cannot not be guaranteed
- Ensuring a long term safe storage requires to compare observations with predictions
  - **decide about corrective actions, remediation techniques**
  - **setting up of both preventive and protective barriers.**
- **Regulatory framework : a stage-gate process**
  - **successive sanctions, no guaranty that the storage permitting process will pass all the gates**
    - exploration : identification of a potential site;
    - characterization, design of the injection infrastructure
    - injection with monitoring and verification
    - closure: surveillance to calibrate the long term prediction of the storage safety and permanency.

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## How can geosciences participate in effective communications ?

- **CO2 plume expansion with time**
  - **what is not seen is perceived as a threat**
- **Remediation**
  - prevention
  - detection of leakage
  - remediation
- **Safety increases with time**
  - **most of the events will happen during the first decades when the storage is fully instrumented and monitored**
  - CO2 dissolves and then sinks
  - CO2 becomes less and less mobile

source BGS

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## Are there relevant examples of effective or ineffective communications for geologic storage or from other fields ?

- **The Lacq project (TOTAL)**
  - communication took time but was effective
- **Barendrecht ?**

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## Questions

- What will make investors comfortable ?
- What geosciences information can create that comfort ?
  - What concepts and approaches for risk communication can be used ?
  - How can geosciences participate in effective communications ?
  - Are there relevant examples of effective or ineffective communications for geologic storage or from other fields ?



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

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

### **1. Purpose of the CSLF**

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

### **2. Function of the CSLF**

The CSLF seeks to:

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

- 2.8 Organize collaboration with the international stakeholder community, including industry, academia, financial institutions, government and non-government organizations; the CSLF is also intended to complement ongoing international cooperation;
- 2.9 Disseminate information and foster knowledge-sharing, in particular among members' demonstration projects;
- 2.10 Build the capacity of Members;
- 2.11 Conduct such other activities to advance achievement of the CSLF's purpose as the Members may determine;
- 2.12 Consult with and consider the views and needs of stakeholders in the activities of the CSLF;
- 2.13 Initiate and support international efforts to explain the value of CCUS, and address issues of public acceptance, legal and market frameworks and promote broad-based adoption of CCUS; and
- 2.14 Support international efforts to promote RD&D and capacity building projects in developing countries.

### **3. Organization of the CSLF**

- 3.1 A Policy Group and a Technical Group oversee the management of the CSLF. Unless otherwise determined by consensus of the Members, each Member will make up to two appointments to the Policy Group and up to two appointments to the Technical Group.
- 3.2 The CSLF operates in a transparent manner. CSLF meetings are open to stakeholders who register for the meeting.
- 3.3 The Policy Group governs the overall framework and policies of the CSLF, periodically reviews the program of collaborative projects, and provides direction to the Secretariat. The Group should meet at least once a year, at times and places to be determined by its appointed representatives. All decisions of the Group will be made by consensus of the Members.
- 3.4 The Technical Group reports to the Policy Group. The Technical Group meets as often as necessary to review the progress of collaborative projects, identify promising directions for the research, and make recommendations to the Policy Group on needed actions.
- 3.5 The CSLF meets at such times and places as determined by the Policy Group. The Technical Group and Task Forces will meet at times that they decide in coordination with the Secretariat.
- 3.6 The principal coordinator of the CSLF's communications and activities is the CSLF Secretariat. The Secretariat: (1) organizes the meetings of the CSLF and its sub-groups, (2) arranges special activities such as teleconferences and workshops, (3) receives and forwards new membership requests to the Policy Group, (4)

coordinates communications with regard to CSLF activities and their status, (5) acts as a clearing house of information for the CSLF, (6) maintains procedures for key functions that are approved by the Policy Group, and (7) performs such other tasks as the Policy Group directs. The focus of the Secretariat is administrative. The Secretariat does not act on matters of substance except as specifically instructed by the Policy Group.

- 3.7 The Secretariat may, as required, use the services of personnel employed by the Members and made available to the Secretariat. Unless otherwise provided in writing, such personnel are remunerated by their respective employers and will remain subject to their employers' conditions of employment.
- 3.8 The U.S. Department of Energy acts as the CSLF Secretariat unless otherwise decided by consensus of the Members.
- 3.9 Each Member individually determines the nature of its participation in the CSLF activities.

#### **4 Membership**

- 4.1 This Charter, which is administrative in nature, does not create any legally binding obligations between or among its Members. Each Member should conduct the activities contemplated by this Charter in accordance with the laws under which it operates and the international instruments to which its government is a party.
- 4.2 The CSLF is open to other national governmental entities and its membership will be decided by the Policy Group.
- 4.3 Technical and other experts from within and without CSLF Member organizations may participate in RD&D projects conducted under the auspices of the CSLF. These projects may be initiated either by the Policy Group or the Technical Group.

#### **5 Funding**

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

#### **6 Open Research and Intellectual Property**

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

## **7. Commencement, Modification, Withdrawal, and Discontinuation**

### 7.1 Commencement and Modification

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

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

### 7.2 Withdrawal and Discontinuation

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

## **8. Counterparts**

This Charter may be signed in counterpart.



## CARBON SEQUESTRATION LEADERSHIP FORUM 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.

**Carbon Sequestration leadership forum**

[www.cslforum.org](http://www.cslforum.org)



**CSLF Strategic Plan  
Second Update  
2011-2016**

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# 1. INTRODUCTION

This is the Second Update of the CSLF Strategic Plan. The CSLF Strategic Plan was initially prepared in 2004 and was updated in 2009. The 2009 update set out a strategy to carry the CSLF through June 2013, when the CSLF Charter was then set to expire. In preparation for the expected extension of the term of the CSLF beyond 2013 at the 2011 Ministerial in Beijing, this Second Update to the Strategic Plan provides a strategy for the CSLF through 2016, three years beyond the original expiration date of the CSLF Charter.

One additional major change to the Charter that will affect the strategy and activities of the CSLF is anticipated at the Beijing Ministerial: the focus of the CSLF is expected to be broadened from Carbon Capture and Storage (CCS) to Carbon Capture, Utilization and Storage (CCUS). This broadening recognizes that beneficial reuse is another potentially viable option for captured carbon dioxide (CO<sub>2</sub>). Beneficial reuse includes a range of applications for CO<sub>2</sub>, including Enhanced Oil Recovery (EOR, already envisioned in CCS), chemical and food production, as well as other uses. In some cases of these applications – many EOR projects, for example – captured CO<sub>2</sub> would be a replacement for natural sources of CO<sub>2</sub>.

The technical, economic and institutional landscape for CCUS has changed since 2009 and this also needs to be reflected in the new strategy. Considerable progress has been made on the technology and practice of CCS and the world stands ready to build and operate many industrial-scale, fully-integrated CCS projects, potentially exceeding the 20 projects by 2020 called for by the CSLF and International Energy Agency in 2007. On the other hand, the economic downturn in many countries, the large investments required, and a continuing lack of public understanding have presented major hurdles to these projects and a number of them have been cancelled. A major challenge facing the CCUS community is to bring enough diverse industrial-scale integrated projects into operation with adequate information sharing to ensure that CCUS becomes widely commercial on a global scale by 2020. This will put a premium on international collaboration through the CSLF and other collaborative mechanisms.

## Objective of this Update to the Strategic Plan

The objective of this Second Update to the CSLF Strategic Plan is to lay the groundwork for effective international collaboration through the CSLF on those activities necessary for CCUS to become widely commercial in both industrialized and developing countries. The Strategic Plan Second Update builds on the ongoing activities and demonstrated capabilities of the CSLF, takes into account the current global situation of CCUS, and is aligned with other international collaborations on CCUS.

## Organization of this Update

The next section describes the framework under which this Update is being developed, including external and internal factors affecting the CSLF and defines the overall strategy. The sections following that describe the strategies and action plans of the three major organizational components of the CSLF: the Policy Group, Technical Group and Secretariat.

## 2. STRATEGIC FRAMEWORK AND STRATEGY

The development of a strategic plan for the CSLF requires understanding the objectives of the CSLF and how the external environment affects achievement of those objectives. It also requires understanding the organizational structure and strategic position of the CSLF. The strategic position consists of the current status of activities, as well as the strengths and weaknesses of the CSLF, its opportunities and threats, and its relationships to other organizations with similar goals. The strategy to achieve the objectives must then take into account the internal and external factors and take best advantage of the strategic position of the CSLF.

### CSLF Objectives

The purpose of the CSLF, as stated in its Charter is:

- ✓ “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 carbon capture and storage.

This could include promoting the appropriate technical, political, economic and regulatory environments for the research, development, demonstration and commercial deployment of such technology.”

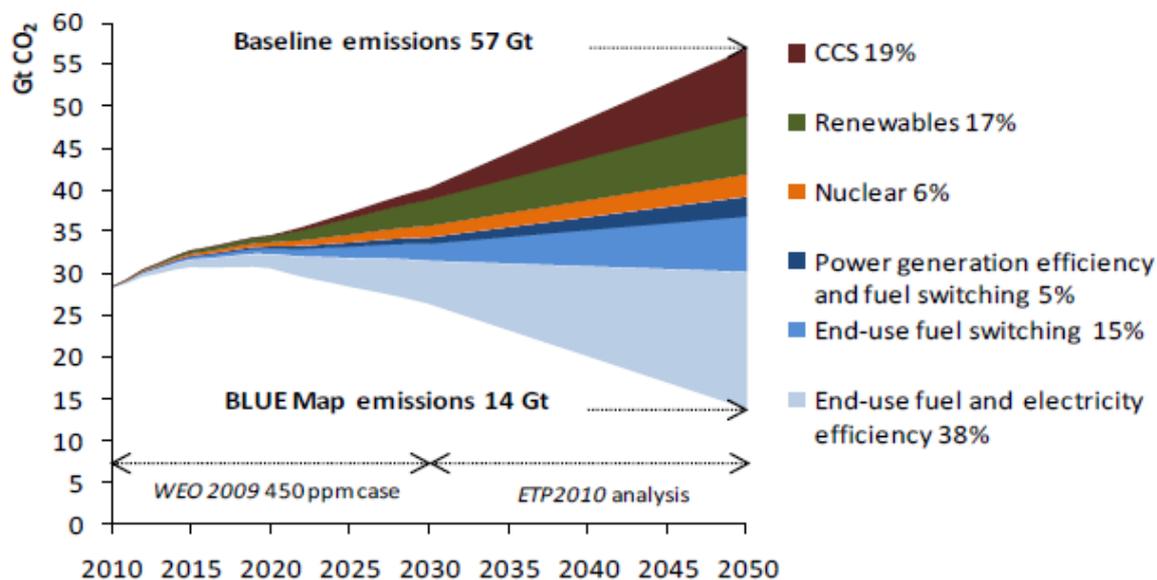
### External Environment

The major driver for CCUS is the need to reduce greenhouse gas emissions and, in particular, CO<sub>2</sub> emissions, coupled with the needs of Member countries for continued economic stability and growth, as well as energy security. The widespread global use of fossil fuels is projected to continue in large industrial and power generation facilities for decades to come. The broad abundance and low cost of fossil fuels, as well as the immaturity and high cost of alternatives, make large-scale switching from fossil fuels difficult in the near term. The use of fossil fuels must become more efficient and less carbon intensive. For many large fossil fuel power generation and industrial facilities, CCUS is the only method to substantially reduce CO<sub>2</sub> emissions.

#### The Potential Role of CCUS

The potential global role that CCUS could play in emission reduction was shown in a recent study by the International Energy Agency (IEA), the results of which are shown in Figure 1. This study projects that CCS in the power and industrial sectors is needed to achieve 19 percent of the emission reduction required to keep CO<sub>2</sub> concentrations in the atmosphere below 450 parts per million. This is the level above which the Intergovernmental Panel on Climate Change (IPCC) concluded average temperatures would rise by 2°C, causing serious climate impacts. According to more recent analyses by the IEA, however, the “Prospect of limiting the global increase in temperature to 2°C is getting bleaker” as increases in CO<sub>2</sub>

emissions and atmospheric concentrations continue to rise to record levels.<sup>1</sup> All this makes the need for rapid deployment of CCUS increasingly vital.



**Figure 1. CO<sub>2</sub> Emission Reduction by Type in an Emission Reduction Scenario**

Source: International Energy Agency, “Energy Technology Perspectives 2010: Scenarios and Strategies to 2050,” Paris: OECD/IEA 2010.

Utilization of CO<sub>2</sub> (the expected new area under the CSLF Charter), especially for EOR, would improve the economics of projects. CO<sub>2</sub> drive EOR is a well-established practice in some regions and has a broader potential worldwide. At the same time, other utilization applications have been relatively unexplored.

### Trends since the 2009 Update

Three trends evident in 2009 have continued to influence the potential for CCUS and the work of the CSLF: continued progress on CCUS, economic challenges and still-unresolved international discussions.

Progress on CCUS technology is accelerating. Interest in CCUS technology has grown and the research community working on it continues to expand. The scope of CCUS research, development and demonstration activities has vastly increased throughout the world. The next step towards development and deployment of CCUS is to develop fully-integrated industrial scale demonstration projects. Many fully-integrated industrial scale demonstration and commercial facilities are now under development.

Economic challenges continue in North America and Europe and may reduce the financial resources available for capital-intensive activities such as CCUS, and the costs of major projects have been escalating. On the other hand, CCUS projects have been part of economic stimulus packages in some countries. The challenge of financing is particularly difficult in developing countries.

<sup>1</sup> [http://www.iea.org/index\\_info.asp?id=1959](http://www.iea.org/index_info.asp?id=1959), accessed June 5, 2011.

International discussions are continuing through the United Nations Framework Commission for Climate Change (UNFCCC) on the arrangements to the second commitment period to the Kyoto Protocol. The status of CCS as a domestic mitigation policy is well accepted, but the debate continues over the use of CCS in the Clean Development Mechanism (CDM).

### Barriers to CCUS

While great progress has been made, significant barriers to CCUS remain. These barriers are summarized in Table 1. Barriers 1 through 5 are policy related while barriers 6 through 14 are technical. Nearly all have economic aspects. This table is very general and the barriers, especially policy barriers, vary by country. More work remains to address each of these barriers. International collaboration through the CSLF, other international organizations and bilateral efforts can help address these barriers and speed up overcoming them.

### International Collaborations

CCUS research, development and demonstration (RD&D) activities, as well as efforts to develop the institutions for CCUS, are being conducted by many CSLF Members and in some non-Member countries. Several jurisdictions also have economic incentives for CCS. In addition to the CSLF, several other international organizations also work to advance CCS:

- The International Energy Agency (IEA) has undertaken a broad array of efforts to further CCS. Some of these are the responsibility of its Working Party on Fossil Fuels; others are carried out by the IEA Secretariat. Two IEA Implementing Agreements are particularly focused on CCS:
  - The IEA Greenhouse Gas R&D Programme (IEA GHG) is an international research collaboration which studies and evaluates technologies that can reduce greenhouse gas emissions derived from the use of fossil fuels. The major focus of the IEA GHG is on CCS.
  - The IEA Clean Coal Centre is a research organization for clean coal technologies. Much of its recent work has focused on CCS in coal-based facilities.
- The Global Carbon Capture and Storage Institute (Global CCS Institute) was launched in 2009 to accelerate the deployment of CCS technologies through 20 fully integrated industrial-scale demonstration projects by 2020. The Global CCS Institute has committed to work collaboratively with the IEA, the CSLF and other CCS organizations.
- At the second Clean Energy Ministerial in April 2011, Energy Ministers from around the world agreed to take action based on the recommendations of the CCUS Action Group (a CEM initiative) to accelerate the global deployment of CCUS technologies.
- Multilateral development banks, such as the World Bank and Asian Development Bank, are starting to include CCS in their activities. The World Bank conducts capacity building activities on CCS and both the World Bank and the Asian Development Bank are exploring financing of CCS in developing countries.

**Table 1. Barriers to Development and Deployment**

<b>Barrier</b>	<b>Progress to Date</b>	<b>Current Situation</b>
1. Inadequate legal/ regulatory frameworks	<ul style="list-style-type: none"> <li>• Various jurisdictions have enacted legislation and regulations for CCS.</li> </ul>	<ul style="list-style-type: none"> <li>• Not all jurisdictions have enacted frameworks</li> <li>• Gaps in legal/regulatory frameworks remain</li> </ul>
2. Gap in commercial financing	<ul style="list-style-type: none"> <li>• Financial incentives have been enacted for demonstration projects in some jurisdictions.</li> </ul>	<ul style="list-style-type: none"> <li>• Except in certain niche markets or for demonstrations with large government incentives, commercial financing is unavailable.</li> </ul>
3. Need for human and institutional capacity	<ul style="list-style-type: none"> <li>• Initial efforts are being made in both industrialized and developing countries.</li> </ul>	<ul style="list-style-type: none"> <li>• Longer-term, more extensive efforts are needed.</li> <li>• Capacity building in developing countries relies on international collaboration.</li> </ul>
4. Lack of public awareness, understanding and support.	<ul style="list-style-type: none"> <li>• Some efforts to create public awareness of CCS, but much less than other greenhouse gas abatement measures.</li> </ul>	<ul style="list-style-type: none"> <li>• Public awareness of the need for CCS, how it works, and its safety remains limited.</li> <li>• Misperceptions abound.</li> </ul>
5. Inadequate international frameworks	<ul style="list-style-type: none"> <li>• CCS is included in London Convention and Protocol.</li> </ul>	<ul style="list-style-type: none"> <li>• London Protocol not ratified so cross-border CO<sub>2</sub> shipments not yet legal.</li> <li>• CCS is not included in international carbon trading mechanisms, but progress is now more likely.</li> </ul>
6. Few industrial-scale integrated projects	<ul style="list-style-type: none"> <li>• Only a few in operation, none in power generation</li> </ul>	<ul style="list-style-type: none"> <li>• Many projects are in various stages of development.</li> </ul>
7. High capture cost	<ul style="list-style-type: none"> <li>• R&amp;D and pilot projects have made some progress.</li> </ul>	<ul style="list-style-type: none"> <li>• Capture costs are still too high.</li> <li>• Cost escalation is a concern.</li> <li>• Only some capture options addressed.</li> <li>• Industrial-scale projects needed.</li> </ul>
8. High energy penalty	<ul style="list-style-type: none"> <li>• Various options are being explored.</li> </ul>	<ul style="list-style-type: none"> <li>• Energy penalty is still too high.</li> <li>• Industrial scale projects are needed.</li> </ul>
9. Limited work on capture from industrial sources	<ul style="list-style-type: none"> <li>• Efforts in this area are limited.</li> </ul>	<ul style="list-style-type: none"> <li>• Significant work is just beginning.</li> </ul>
10. Limited work on CO <sub>2</sub> utilization	<ul style="list-style-type: none"> <li>• Efforts in this area are limited.</li> </ul>	<ul style="list-style-type: none"> <li>• Significant work is just beginning.</li> </ul>
11. Lack of CO <sub>2</sub> transport infrastructure	<ul style="list-style-type: none"> <li>• Transport from sources to storage is mandatory.</li> </ul>	<ul style="list-style-type: none"> <li>• CO<sub>2</sub> pipelines are commercial for EOR, not geologic storage.</li> <li>• Plans for networks being developed.</li> <li>• Ocean transport is not yet developed.</li> </ul>
12. Limited geologic storage experience	<ul style="list-style-type: none"> <li>• Many smaller-scale injections have been conducted.</li> <li>• Enhanced oil recovery (EOR) is widely used in some regions.</li> </ul>	<ul style="list-style-type: none"> <li>• Multiple large-scale injections in diverse formations are beginning.</li> </ul>
13. Need to estimate storage capacity and demonstrate storage integrity	<ul style="list-style-type: none"> <li>• Various regional and national storage capacity estimates have been made.</li> <li>• CSLF has developed storage capacity estimate standards.</li> <li>• Some projects experience has been gained.</li> </ul>	<ul style="list-style-type: none"> <li>• Considerable progress has been made but regional and national numbers could be improved.</li> <li>• More and diverse project experience widely disseminated would enable widespread deployment.</li> </ul>
14. Storage assurance and risk management tools need further development	<ul style="list-style-type: none"> <li>• Measurement, monitoring and accounting (MMA) practices and protocols have been developed.</li> <li>• Risk analysis techniques have been developed.</li> </ul>	<ul style="list-style-type: none"> <li>• More experience with MMA and risk management is needed.</li> <li>• Linkage between technical risk and legal/financial liability is not clear.</li> </ul>

In addition to the international organizations listed above, a number of regional cooperative ventures on CCS are also being implemented. The European Commission aims to achieve 12 up-to-commercial-scale demonstration projects by 2020 across a range of technologies and, within the EU, CCS project network, six demonstration projects already actively exchange information. The Regional Carbon Sequestration Partnerships in the United States and Canada (a CSLF-recognized project) are conducting numerous regional studies. Similarly, the Asia Pacific Economic Cooperation has sponsored several studies on CCS. Each of these activities has also involved collaboration between the public and private sectors.

While not specifically focused on CCS, the Intergovernmental Panel on Climate Change (IPCC) provides an objective source of information about climate change initiatives through assessment on a comprehensive, objective, open and transparent basis, of the latest scientific, technical and socio-economic literature produced worldwide. The IPCC has published a Special Report on Carbon Capture and Storage (2005), updated the inventory guidelines for CCS (2007), and recognized CCS as an important greenhouse gas abatement technology in its Fourth Assessment Report (2008).<sup>2</sup>

## CSLF Organizational Structure

The basic organization of the CSLF is defined in the CSLF Charter as consisting of a Policy Group, a Technical Group and Secretariat. The responsibilities of each of these are delineated in more detail in the CSLF Terms of Reference and Procedures. (See text box.)

Most of the ongoing substantive work of the CSLF takes place in task forces reporting to either the Policy Group, the Technical Group or both, all supported by the CSLF Secretariat. Task forces are created, modified or disbanded, as needed, by the decisions of the Policy Group or Technical Group and are chaired by Members of the CSLF. Participation in the task forces is voluntary and generally consists of experts in the subject matter of the task force. Participation is open to representatives of CSLF Members and, with the permission of the Task Force Chair, to Stakeholders. Numerous expert Stakeholders participate in CSLF task forces. Currently, there are 13 task forces. Of these, four report to the Policy Group, seven report to the Technical Group and two reports to both the Policy Group and Technical Group. Several new task forces are envisioned by this updated Strategic Plan. One Technical Group Task Force, the Task Force to Assess Progress on Technical Issues affecting CCS, has several working groups in specialized areas reporting to it.

The current organizational structure of the CSLF is shown in Figure 2.

## Strategic Position

The strategic position of the CSLF is determined by the status of its ongoing activities, its strengths and weaknesses and the opportunities and threats it faces.

### Status of CSLF Activities

Both the CSLF Policy Group and Technical Group made significant progress in achieving the goals of the CSLF through various task forces established to address specific areas of concern.

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<sup>2</sup> These reports are available at: [http://www.ipcc.ch/publications\\_and\\_data/publications\\_and\\_data\\_reports.shtml](http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml)

## **FROM THE CSLF TERMS OF REFERENCE AND PROCEDURES**

### **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.

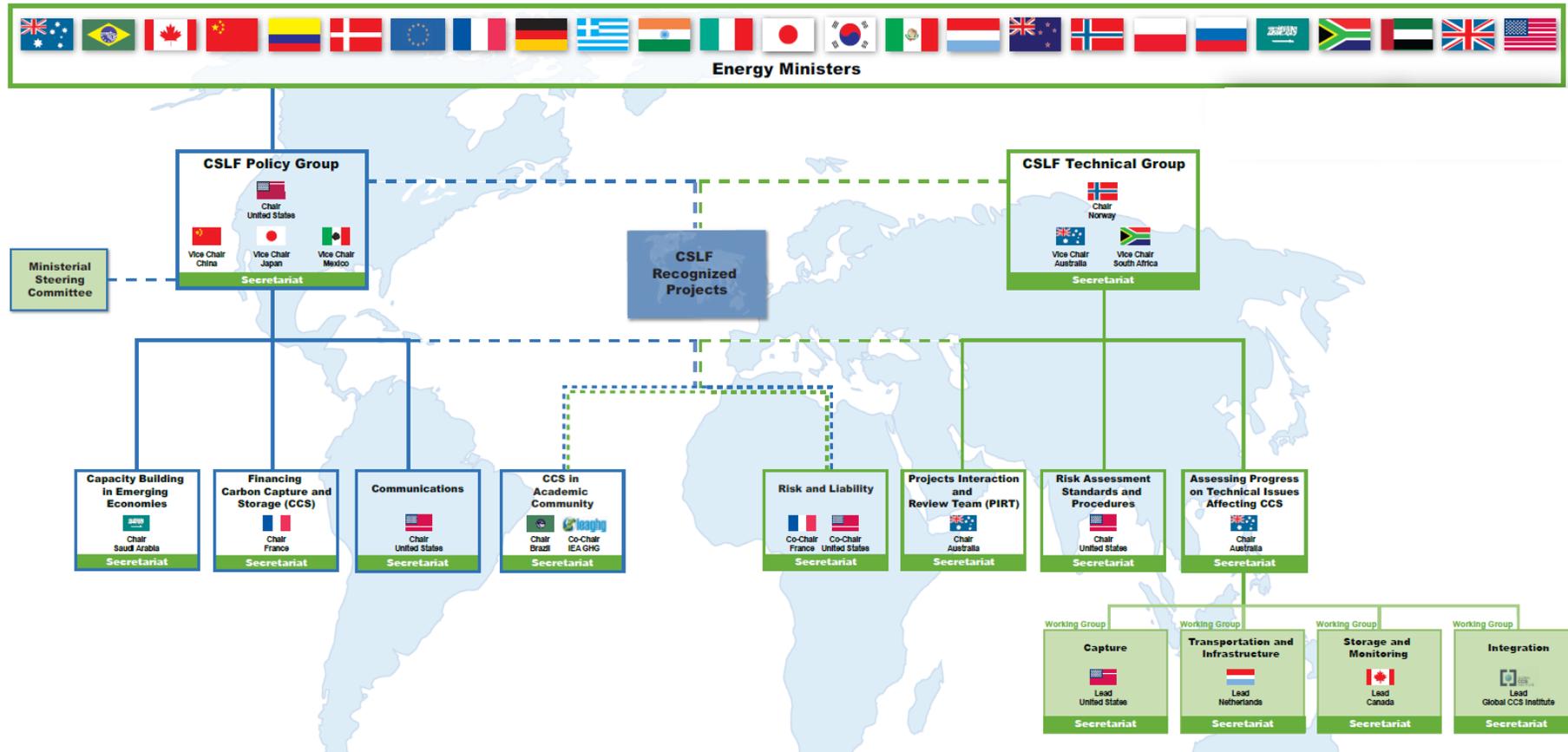
The Chair of the Policy Group will provide information and guidance to the Technical Group on required tasks and initiatives to be undertaken based upon decisions of the Policy Group. The Chair of the Policy Group will also arrange for appropriate exchange of information between both the Policy Group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

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.

Figure 2. CSLF Organizational Chart



Since its inception, both the Policy Group and Technical Group have achieved notable successes that have advanced CCS, for example:

- Implementation of an international capacity building program on CCS;
- Definition of storage site selection criteria;
- Methodology for estimating storage capacity;
- Definition of legal and regulatory issues; and
- Recommendations (with the IEA) on CCS to the G8.

Tables 2 and 3 provide an overview of the achievements and current status of CSLF activities for the Policy Group and Technical Group, respectively. In one achievement involving both Groups, the CSLF has recognized 31 major international projects that advance the state-of-the-art of CCS, each of which makes information publicly available on a global basis. Nine of those projects have been completed.

While much progress has been made, moving CCUS forward will require global cooperation on an unprecedented scale. This cooperation is needed to meet the challenges of advancing the technology, to reduce costs, to engage developing countries, and to collaborate with the private sector to deploy this technology.

#### Strengths, Weaknesses, Opportunities and Threats (SWOT) Analysis

The CSLF's strengths, weaknesses, opportunities and threats remain those identified when this analysis was first performed in 2009 for the first update of the CSLF Strategic Plan. A number of changes since 2009 are indicated in **bold**.

- Strengths: The CSLF has demonstrated several key strengths. Foremost, is that the CSLF has demonstrated global convening power, both to facilitate information exchange on CCS and to bring together experts from around the world to address common problems such as developing standards for risk assessment and storage capacity estimates. CSLF reports are recognized as authoritative reference works worldwide.
- The CSLF is an organization of national governments.
- CSLF Members represent a large portion of the world's energy supply and demand and represent both industrialized and developing countries.
- The participation of developing countries, in particular, is a unique strength. Until the recent formation of the Global CCS Institute, the CSLF was the only international organization focused solely on CCS.
- Stakeholders participate in its task forces and activities.
- **The scope of the CSLF is expanding to include utilization.**
- **The first funded project of the CSLF (capacity building) sets a precedent for further funding of projects.**

These characteristics make the CSLF a unique forum for ongoing collaboration on CCS.

**Table 2. CSLF Policy Group Accomplishments and Their Status**

Accomplishment	Significance	Status
1. CSLF Strategic Plan 2004, 2009 Update and 2011 Update	<ul style="list-style-type: none"> <li>The Strategic Plan represents consensus of the Members on future activities.</li> </ul>	<ul style="list-style-type: none"> <li>Strategic Plan has been agreed upon by the Members.</li> <li>The term of the CSLF Charter is anticipated to be extended indefinitely beyond 2013 at the 2011 Ministerial.</li> </ul>
2. Recommendations to the G8	<ul style="list-style-type: none"> <li>These recommendations form the basis for activities to advance CCS throughout the world.</li> </ul>	<ul style="list-style-type: none"> <li>In response to the G8, the CSLF and IEA made recommendations on how to advance CCS in near-term applications.</li> </ul>
3. Progress towards a financing approach	<ul style="list-style-type: none"> <li>Financing is a major constraint on CCS, in both industrialized and developing countries.</li> </ul>	<ul style="list-style-type: none"> <li>Work is ongoing. Several workshops on financing have been held and a Task Force continues work in this area.</li> </ul>
4. Communications on CCS	<ul style="list-style-type: none"> <li>Public understanding is critical to CCS deployment.</li> </ul>	<ul style="list-style-type: none"> <li>Public outreach materials for use by Members have been developed.</li> <li>Daily email news on CCS is provided to CSLF Member and Stakeholders.</li> </ul>
5. CSLF capacity building initiative	<ul style="list-style-type: none"> <li>This is a major demonstration of commitment to developing country Members.</li> </ul>	<ul style="list-style-type: none"> <li>Six capacity building workshops have been held so far in four countries. Each has received enthusiastic response from participants and expressions of interest for more.</li> <li>The CSLF Capacity Building Fund was established with approximately \$3 million in commitments.</li> <li>Nine projects in five countries are currently underway using the Fund and more are under consideration.</li> <li>CSLF Collaborates with World Bank and Global CCS Institute.</li> </ul>
6. Guidelines for legal-regulatory frameworks	<ul style="list-style-type: none"> <li>Legal and regulatory frameworks are necessary to CCS deployment.</li> </ul>	<ul style="list-style-type: none"> <li>Worked with IEA to hold two workshops.</li> <li>Developed guidelines which accelerated consideration of legal and regulatory framework.</li> <li>By agreement, IEA has lead in further work in this area.</li> </ul>
7. CCS in the academic community	<ul style="list-style-type: none"> <li>The academic community needs to teach and conduct advanced research on CCUS.</li> </ul>	<ul style="list-style-type: none"> <li>Surveyed academic programs on CCS in North and South America and Europe; many programs were identified.</li> </ul>
8. Project recognition	<ul style="list-style-type: none"> <li>This provides a basis for information sharing on 31 of the most important projects throughout the world covering all aspects of CCS.</li> </ul>	<ul style="list-style-type: none"> <li>Projects report progress regularly to the CSLF.</li> <li>Completed projects have already created the basis for later projects to build on their findings.</li> </ul>

**Table 3. CSLF Technical Group Accomplishments and Their Status**

Accomplishment	Significance	Status
1. CSLF Technology Roadmap to identify and address gaps in R&D	<ul style="list-style-type: none"> <li>• The CSLF Technology Roadmap reflects a consensus of leading international experts on the technical developments necessary to develop and deploy all aspects of CCS.</li> <li>• 2011 Roadmap emphasizes integration of complete value chain, needs to achieve commercial viability and global storage potential.</li> </ul>	<ul style="list-style-type: none"> <li>• The CSLF Technology Roadmap was first completed in 2004 and updated in 2009, 2010 and 2011.</li> <li>• The CSLF Technology Roadmap is widely accepted.</li> </ul>
2. Technology Gaps Analysis	<ul style="list-style-type: none"> <li>• Gaps analysis is a global consensus of experts on areas where further research, development and demonstration are needed.</li> </ul>	<ul style="list-style-type: none"> <li>• Outcomes have led to identification of a suite of future areas of activities.</li> <li>• Extensive gaps analysis activities are a continuing priority.</li> </ul>
3. International standards for storage capacity estimates	<ul style="list-style-type: none"> <li>• CSLF storage capacity estimation has gained international acceptance.</li> <li>• Methodology establishes a consistent basis for estimating, comparing and valuing geologic storage capacity for CO<sub>2</sub>.</li> </ul>	<ul style="list-style-type: none"> <li>• This capacity estimation methodology has been developed on a theoretical basis by the foremost experts in the world.</li> </ul>
4. Assessment and identification of gaps in MMV	<ul style="list-style-type: none"> <li>• This assessment describes gaps in MMV technologies and practices where further R&amp;D is required.</li> </ul>	<ul style="list-style-type: none"> <li>• Task Force report is complete.</li> <li>• Additional work to close identified gaps will require further study incorporating lessons learned from multiple projects.</li> </ul>
5. Technical risk analysis	<ul style="list-style-type: none"> <li>• Technical risk assessment is a key enabler of commercial deployment and public acceptance.</li> </ul>	<ul style="list-style-type: none"> <li>• Risk assessment standards and procedures examined.</li> <li>• Technical risks of injection and storage are being studied.</li> <li>• A Phase I Task Force report on risk identification and assessment has been completed.</li> </ul>
6. Interactive information exchange	<ul style="list-style-type: none"> <li>• Facilitates the exchange of technical information and real-world experience among project sponsors.</li> <li>• Knowledge sharing and information exchange will accelerate progress in commercialization of CCS technologies.</li> </ul>	<ul style="list-style-type: none"> <li>• An interactive forum has been successfully piloted with positive feedback from participants.</li> <li>• Planning for additional activities is underway.</li> </ul>

As a voluntary organization of governments, the CSLF provides the basis for open discussions among governments and it does not impose the requirements of a funding organization.

Weaknesses: Being a voluntary organization, the CSLF has a limited internal budget and staffing resources. Also, it is not able to directly fund some of its outreach activities.

Opportunities: CCUS is now in transition from a largely experimental technology to a technology that is to be demonstrated at a commercial scale and will begin to be deployed commercially. Governments throughout the world can benefit from the open discussions and collaboration opportunities offered by the CSLF. Stakeholders can benefit from participation in the CSLF activities.

**The precedent set by the CSLF Capacity Building Fund may indicate a way to overcome the weakness of the CSLF being a voluntary organization.**

The two other international organizations with a major focus on CCS—the IEA and the Global CCS Institute—have complementary strengths. These provide the CSLF with the opportunities for cooperation that will greatly leverage its resources.

Threats: The primary threats faced by the CSLF are not threats to the CSLF as an organization, but rather the barriers—noted earlier—faced by CCUS as a greenhouse gas mitigation measure. Perhaps most important of those is that CCS is little known by the public and political decision makers. It is new and complex and, therefore, subject to considerable misunderstanding; it requires much more political championship globally.

## Strategy

The CSLF will continue to provide an active forum for international collaboration to lower both policy and technical barriers to the development and widespread global deployment of CCS (or CCUS, given a widened mandate in a revised charter). The focus is in the areas in which the CSLF can provide the greatest value for its Members, including:

- Collaboration by experts from around the world to develop and improve policies, standards and procedures to be used by Members and make those more broadly available;
- Information exchange to accelerate or improve the policy development or technical progress of Members;
- Idea generation to advance CCUS for follow-up by Members individually or collaboratively;
- Capacity building in Member countries;
- Joint action to achieve mutual goals while reducing costs and accelerating progress; and
- Consensus facilitation in international policy discussions related to CCUS.

While remaining an organization of national governments, the CSLF invites the active involvement of non-governmental stakeholder experts to advance its initiatives.

The CSLF also works closely with other international organizations to advance CCUS, further broadening the scope and reach of international collaboration.

### Action Plans to Implement the Strategy

Action Plans have been developed for future activities of the Policy Group, Technical Group and Secretariat. Each of these plans is designed to address a major challenge to the development and commercialization of CCUS or to facilitate the operation of the CSLF. There are a total of 22 Action Plans, six for the Policy Group, eleven for the Technical Group and five for the Secretariat. Each of the Policy Group and Technical Group Action Plans will be implemented by a task force. In some cases, these task forces have yet to be established.

Table 4 below enumerates these Action Plans. They are described in the following three sections.

**Table 4. CSLF Strategy Action Plans 2011-2016**

Action Plan	Priority
<b>Policy Group Action Plans</b>	
P1 – Bridging the Financing Gap	High
P2 – Financing Projects with CCS in Developing Countries	High
P3 – Incentives Registry	High
P4 – Capacity Building	Very High
P5 – Communications	High
P6 – CCS in Academic Community	High
<b>Technical Group Action Plans</b>	
T1 – Technology Gaps Closure	Very High
T2 – Best-practice Knowledge Sharing	High
T3 – Energy Penalty Reduction	Very High
T4 – CCS with Industrial Emissions Sources	High
T5 – Carbon-neutral and Carbon-negative CCS with Biomass	High
T6 – CO <sub>2</sub> Transport and Compression	High
T7 – Storage and Monitoring for Commercial Projects	Very High
T8 – Technical Challenges of using CO <sub>2</sub> EOR for CCS	Very High
T9 – Risk and Liability	Very High
T10 – CO <sub>2</sub> Utilization Options	Very High
T11 – Competition of Geologic Storage with Production of Other Resources	High
<b>Secretariat Action Plans</b>	
S1 – CSLF Administration	Very High
S2 – Administration of CSLF Capacity Building Program	Very High
S3 – Stakeholder Engagement	High
S4 – International Collaboration	High
S5 – Providing Information on CCS in International Negotiations	High

### 3. POLICY GROUP STRATEGY AND ACTION PLANS

Under the CSLF Charter, 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 Policy Group has developed Action Plans in four areas implemented by Task Forces that address the policy and institutional barriers identified in Table 1:

- Financing (Barrier addressed: gaps in commercial financing);
- Capacity Building (Barrier addressed: need for human and institutional capacity);
- Communications (Barriers addressed: lack of public awareness, understanding and support; and need for human and institutional capacity); and
- CCS in the Academic Community (Barrier addressed: need for human and institutional capacity).

Each area has one or more Action Plans as described below. The Policy Group also decides on recognition of projects recommended by the Technical Group.

Legal and regulatory frameworks have previously been addressed by the Policy Group in collaboration with the IEA. The CSLF has agreed that the IEA will take the lead in international collaboration in this area with the CSLF working with the IEA, as needed.

#### Financing

CCS technologies have a critical role in mitigating carbon emissions to achieve stabilization of atmospheric CO<sub>2</sub> concentrations. In order for this potential to be achieved, demonstration projects must make significant progress and the technology must then move from demonstration to commercial deployment. In moving to deployment, projects with CCS must earn revenues adequate to cover costs and attract private investment by offering competitive returns. A major difference between demonstration and commercial projects is that there are no commercial “CCS projects.” Instead, commercial industrial projects and power plants with CCS must both produce output and raise capital competitively.

The CSLF and other organizations—in particular, the Asian Development Bank, IEA, and Global CCS Institute—have recently analyzed the potential to finance CCS in global markets. Identifying potential barriers to and opportunities for investment and funding to facilitate projects is recognized as the key issue for the deployment of CCS. In Europe, an analysis of CCS Costs by the Zero Emission Platform concluded that, following the European Union (EU) CCS demonstration program, post-demonstration CCS in the EU will be cost-competitive in the early 2020s with other sources of low-carbon power such as on- or offshore wind, solar power and nuclear (not including natural gas, currently priced well below \$8/Million Btu).

In Financing Task Force activities, funding models in different parts of the world were presented by Alberta, Japan CCS, and several private companies (GDF-Suez, Conoco and Duke Power). Each model showed the value of adapting tools to regional strengths and weaknesses and project features in deploying projects with CCS.

The modeling showed that no single incentive was sufficient. The Task Force concluded that a suite of incentives and funding models are needed for governments to mobilize private

investment capital. These must be tailored to regional attributes and development priorities (e.g., access to coal and fuels, power pricing, features of CCS sites, public attitudes, competing supply). The Task Force further concluded that the CSLF should support member countries in developing a “toolkit” of approaches and funding models that offers multiple combinations of incentives, which are negotiated.

Action Plan P1: Bridging the Financing Gap

**Responsibility:** Financing Task Force

Given global turmoil in credit markets since 2008, this activity will be ongoing. Similarly, lack of progress in negotiating a global climate regime under UNFCCC requires that alternative approaches be developed. Such approaches would complement any resolutions that emerge from UNFCCC or from other high level forums such as G20. In the absence of cap and trade, other funding approaches for financial incentives must be explored.

**Action:** The CSLF will explore through the Financing Task Force, and in collaboration with other organizations, the most effective way to overcome the gap between the costs and incentives available for CCS, in the absence of adequate prices for GHG savings (carbon prices), in order to accelerate early deployment of CCS. It will engage with the financial community and develop a financing roadmap and multiple options or approaches based on case studies of project successes and failures. To the extent that it is available and appropriate, analyses will be conducted using a financial analysis model of CCS currently being developed by the World Bank.

**Outcome:** Identification and evaluation of a suite of policies that governments could use to promote to facilitate private investment in industrial projects with CCS.

**Milestones:** Assembly of project case studies (with IEA, Global CCS Institute) *Dec. 2011*  
 Ongoing engagement (or interviews) of financial community *2012*  
 Outline of options and approaches *Summer 2012*  
 (modified CSLF Financing Roadmap)  
 Updates *2013-2015*

**Priority:** High

Action Plan P2: Financing Projects with CCS in Developing Countries

**Responsibility:** Financing Task Force working with Asian Development Bank

Due to their size and technical complexity, projects with CCS fundamentally involve international financing and engineering; no single country possesses all needed technologies. Progress in developing countries will entail many of the same engineering firms and key vendors as those in OECD countries. That experience is essential to commercial progress worldwide, and needs to be exchanged among CSLF Members.

**Action:** Update perspectives and investment outlook from industry, capital sources, and Stakeholders by interviews and attending other forums on the framework

of risks and rewards for commercial deployment of projects with CCS in developing countries and potential financing approaches for those projects.

Work with World Bank, Asian Development Bank, key countries on financing options for projects with CCS in emerging economies. Participate in multilateral financing fora.

**Outcome:** Report by the CSLF Financing Task Force

**Milestones:** Report from the Task Force. *Summer 2012*

**Priority:** High

### Action Plan P3: Incentives Registry

**Responsibility:** CSLF Secretariat

**Action:** The CSLF will update and publish its Incentive Registry and maintain its currency through the CSLF Members.

This database will provide information on the types of incentives available to commercial projects with CCS. The data will be displayed at national and sub-national levels (e.g., country, state or province) including the type of incentive (e.g., capital subsidy, tax credit, feed-in tariff, etc).

The database will be prepared in cooperation with IEA and the Global CCS Institute.

**Outcome:** A searchable database that provides current information to interested parties

**Milestones:** Updated Registry *2012 and Ongoing*

**Priority:** High

## Capacity Building

The CSLF has conducted very successful capacity building activities since 2005. Deployment of CCS will require the building of skills and expertise, as well as creating institutional capability in both the public and private sectors. This will be a challenge for all CSLF Members, but especially developing country Members.

To achieve worldwide commercial deployment as early and effectively as possible it is critical that countries share their experience and know-how so each can enhance its own capacity to effectively deploy CCS.

The CSLF Capacity Building Program Plan, approved by the CSLF Policy Group and endorsed by Ministers in 2009, defines the mission of the CSLF Capacity Building Program as assisting all CSLF Members to develop the information, tools, skills, expertise and institutions required to implement CCS demonstrations and then move rapidly into commercial operation. The major focus of the Program is on meeting the needs of developing country Members, although all Members may participate in its activities.

The Program Plan further defines four Program initiatives:

- Disseminate practical information,
- Build capacity in emerging economies,
- Assist government and regulatory agencies, and
- Build academic and research institutions for CCS.

The capacity building activity is unique in that it is the only CSLF activity specifically funded by its Members. To this end, a CSLF Capacity Building Fund has been created with contributions of approximately US\$3 million. In order to ensure proper management of the Fund, the Capacity Building Governing Council has been established to be responsible for the governance of the Fund.

The primary responsibility for capacity building concepts lies with the Policy Group Capacity Building Task Force. A country-driven approach to project identification and implementation has been developed to ensure responsiveness to the real needs of Members. Nine capacity building projects have been initiated to date using financial resources from the Fund and others may be initiated in the future. CSLF capacity building activities are coordinated with those of the World Bank and the Global CCS Institute.

#### Action Plan P4: Capacity Building

**Responsibilities:** Capacity Building Task Force  
Capacity Building Governing Council (for the Fund)  
Secretariat (day-to-day activities)

**Action:** The CSLF will continue to develop, implement and maintain a capacity building program tailored to the needs of each Member, subject to available resources. In addition, the Secretariat, under the direction of the Capacity Building Task Force and Governing Council Chairs, will be charged with the responsibility to carry out the day-to-day activities required to coordinate and execute the Capacity Building Program, including:

- Implement capacity building projects,
- Seek funding for capacity building activities,
- Ensure that information developed is effectively disseminated.

**Outcome:** Building of capacity in CSLF Members is responsive to their expressed needs.  
Dissemination and sharing of information is effective.

**Milestones:** Possible selection of additional projects **2011**  
Evaluation of lessons learned from first projects  
Report and Workshop **Summer 2012**  
Funding obtained and second round of projects **Fall 2012**  
Further rounds of funding and projects **Annual**

**Priority:** Very High

## Communications

Public awareness and acceptability for CCS falls into two areas: The global aspects of CCS as an important mitigation technology; and the local aspects of developing transportation and storage projects.

The CSLF will continue to focus on the global aspects of CCS as an important mitigation technology, rather than the development of storage projects locally. Project acceptability will be highly dependent on local conditions, which could be significantly different among locations. Individual CSLF Members, project developers and others are best suited to doing local outreach.

CSLF communications activities will continue to include the development of tools and informational materials that can be used by the CSLF and Member representatives, organizations such as the IEA and the GGCSI, Stakeholders (industry and NGOs), policy makers, regulators and project developers in order to promote the positive aspects of CCS.

### Action Plan P5: Communications

**Responsibility:** Policy Group Communications Task Force

**Action:** Communications Task Force to continue refining an overall CSLF Communications Plan that includes the development of new materials and update of existing materials for CCS public awareness on the global aspects of CCS as an important mitigation technology. Annex 1 presents more detail on planned Communications activities.

**Outcome:** The visibility of both the CSLF and CCS as a viable technology is raised and key stakeholders and audiences are engaged with timely information.

<b>Milestones:</b>	Web site development/updating	<b>Ongoing</b>
	Members identify CSLF spokespersons	<b>Ongoing</b>
	Prepare calendar of CCS events	<b>Ongoing</b>
	Communications vehicles/talking points	<b>Ongoing</b>
	Communications materials/standard speech	<b>Ongoing</b>
	Communications materials/PowerPoint presentation	<b>Ongoing</b>
	Identify conference/speaking venues	<b>Ongoing</b>

**Priority:** High

## CCS in the Academic Community

Academic experts and institutions are necessary to conduct much of the research to develop CCS technologies and to educate future CCS experts and practitioners. Recognizing this, a Task Force was created in 2009 to develop contacts within the academic community, identify academic perspectives and programs on CCS for universities in CSLF Member countries, and determine the path forward for the CSLF in this area.

The Task Force is now reaching completion of Phase I activities, marked by the finalization of the first combined report on existing academic CCS programs and the CSLF development of a dedicated Bulletin Board as a forum for academic discussion. Once the first Phase has been finalized, the second Phase will begin with an analysis of the survey report and collation into a database to be made available to academics; and further gap analysis will further identify where CSLF could target future activities. One such future activity for the Task Force would be to investigate an exchange program for university professors in CCS curricula to enhance collaborations, strengthening the CCS network and information exchange within the academic community.

Following gap analysis of existing CCS programs, should it prove a priority, it will be possible to explore key areas which CSLF may wish to develop and enhance through strategic course material for CSLF Members. The Task Force may also consider the progress of CCS in academia, the growth of graduate students to assist decisions and targeting of investment, and dedicated meetings to provide a forum with academic institutions. The Task Force will align its activities with the Capacity Building Task Force.

### Action Plan P6: CCS in the Academic Community

<b>Responsibility:</b>	Task Force on CCS in the Academic Community (This is a joint responsibility of the Policy Group and Technical Group.)																		
<b>Action:</b>	The CSLF will identify and review the international development of academic CCS programs, encourage academic student/researcher collaboration, performing gap analysis to target future activities whilst enhancing the developments of strategic curricula for graduate and post-graduate programs.																		
<b>Outcome:</b>	Programs are identified and catalogued. Academic network developed. Proposals for curricula developed.																		
<b>Milestones:</b>	<table><tr><td>First report on existing CCS programs</td><td><b>September 2011</b></td></tr><tr><td>Update of report on CCS programs</td><td><b>Ongoing</b></td></tr><tr><td>Analysis of CCS programs and collation into database</td><td><b>March 2012</b></td></tr><tr><td>Database available to academics</td><td><b>December 2012</b></td></tr><tr><td>Gap Analysis to identify curricula proposals</td><td><b>2013</b></td></tr><tr><td>Proposals for CSLF curricula</td><td><b>2013</b></td></tr><tr><td>Implementation of curricula proposals</td><td><b>2014</b></td></tr><tr><td>Dedicated report of activities</td><td><b>2015</b></td></tr><tr><td>Review Task Force activities</td><td><b>Ongoing</b></td></tr></table>	First report on existing CCS programs	<b>September 2011</b>	Update of report on CCS programs	<b>Ongoing</b>	Analysis of CCS programs and collation into database	<b>March 2012</b>	Database available to academics	<b>December 2012</b>	Gap Analysis to identify curricula proposals	<b>2013</b>	Proposals for CSLF curricula	<b>2013</b>	Implementation of curricula proposals	<b>2014</b>	Dedicated report of activities	<b>2015</b>	Review Task Force activities	<b>Ongoing</b>
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Dedicated report of activities	<b>2015</b>																		
Review Task Force activities	<b>Ongoing</b>																		
<b>Priority:</b>	High																		

## 4. TECHNICAL GROUP STRATEGY AND ACTION PLANS

According to the CSLF Charter the CSLF Technical Group “reviews the progress of collaborative projects, identifies promising directions for the research, and makes recommendations to the Policy Group on needed actions.” Specific responsibilities are delineated in the CSLF Terms of Reference and Procedure (Text Box, page 7).

The Technical Group’s strategy has Action Plans in five broad areas which address the technical barriers identified in Table 1:

- Advancing Technical Collaboration (Barriers addressed: all technical barriers);
- Capture (Barriers addressed: high capture cost, high energy penalty, and limited work on capture from industrial sources and CO<sub>2</sub> utilization );
- Transport (Barrier addressed: lack of CO<sub>2</sub> infrastructure);
- Storage and Utilization (Barriers addressed: limited geologic storage experience, need to estimate storage capacity and demonstrate storage integrity, and storage assurance and risk management tools need further development); and
- Understanding the Impacts (Barrier addressed: storage assurance and risk management tools need further development).

In addition to work on these Action Plans, the Technical Group recommends projects to the Policy Group for recognition.

### Advancing Technical Collaboration

The Technical Group will continue and expand its efforts to advance technical collaboration among its Members and Stakeholders. The keystones guiding these efforts are the CSLF Technology Roadmap and Technology Gaps Analyses. Both are vital methods of identifying areas of CCUS development that can be addressed through international collaboration or can be taken up by CSLF Members or Stakeholders.

Industrial-scale integrated projects will be going into operation in various parts of the world in the next several years, particularly in power generation. This makes the need for best-practice knowledge sharing even more important.

#### Action Plan T1: Technology Gaps Closure

**Responsibility:** Task Force on Assessing Technical Issues that Affect CCS

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

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

**Milestones:** Review of CCS technology gaps and related issues **Yearly**  
Update of CSLF Technology Roadmap (Module 3) **Yearly/Biannually**

Thematic reports on the status of CCS technology gaps/issues **TBD 2012-2016**  
**Priority:** Very High

Action Plan T2: Best-practice Knowledge Sharing

**Responsibility:** Projects Interaction and Review Team

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

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

**Milestones:** Thematic interactive projects “lessons learned” workshops **TBD 2012-2016**  
 Update of CSLF Technology Roadmap (Modules 1, 2, and 4) **Yearly**  
 Thematic reports on lessons learned **TBD 2012-2016**  
 Development of interactive “lessons learned” references (jointly with Communications Task Force) **TBD 2015-2016**

**Priority:** High

**Capture**

A large amount of energy is required in most capture technologies to separate carbon dioxide from other gas streams and compress it for geologic storage. This energy penalty adds significantly to the cost of capture and reduces the effectiveness of the capture. Reducing the energy penalty would improve both the technical and economic viability of capture.

As much as half of the potential emission reductions from CCUS are estimated to be from industrial process sources other than power generation or natural gas separation. Industrial applications for CCUS vary widely and, in some industries, CCUS is the only significant carbon abatement option. Yet, industrial sources have received far less attention than power generation and relatively few proposed demonstration projects involve industrial sources.

Combining CCUS for energy production with sustainably-grown biomass has the potential to be either carbon neutral or carbon negative in facilities where the biomass is either the sole feedstock or, in adequate proportions, is a co-feedstock with fossil fuels. The opportunities and constraints need to be better understood.

Action Plan T3: Energy Penalty Reduction

**Responsibility:** Technical Group/New Task Force or Working Group

**Action:** The Technical Group will identify technological progress and any new research needs for reducing the energy penalty for CCS, both for traditional CO<sub>2</sub> capture processes and new breakthrough technologies.

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

**Milestones:** Workshop to document knowledge and experiences of “early mover” projects **TBD 2013**  
 Report on successful trends and breakthroughs **TBD 2014**

**Priority:** Very High

Action Plan T4: CCS with Industrial Emissions Sources

**Responsibility:** Technical Group/New Task Force or Working Group

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

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

**Milestones:** Technology workshops on CCS for industrial sources **TBD 2013-2016**  
 Outreach activities for CO<sub>2</sub>-intensive industries **TBD 2012-2016**  
 Reports on progress and issues unique to CCS with industrial sources **TBD 2013-2016**

**Priority:** High

Action Plan T5: Carbon-neutral and Carbon-negative CCS with Biomass

**Responsibility:** Technical Group/New Task Force or Working Group

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

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

**Milestones:** Biomass CCS technical workshop **TBD 2013**  
 Interim Report **TBD 2014**  
 Final Report **TBD 2015**

**Priority:** High

## Transport

A number of CO<sub>2</sub> pipelines are already in operation and many others are likely to be planned and built. It is important for governments, pipeline developers and operators and affected stakeholders to set appropriated standards for the construction, operation and maintenance of such standards.

Action Plan T6: CO<sub>2</sub> Transport and Compression

**Responsibility:** Technical Group/New or Existing Task Force or Working Group

- Action:** The Technical Group will review technologies and assess pipeline standards for CO<sub>2</sub> transport, in particular in relation to impurities in the CO<sub>2</sub> stream. Issues such as thermodynamics, fluid dynamics, and materials of construction will be considered. Alternatives to pipelines, such as ship transport, will also be assessed.
- Outcome:** Identification of optimum technical CO<sub>2</sub> transport strategies, both for pipeline and non-pipeline alternatives. Assessment of purity issues as they apply to CO<sub>2</sub> transport. Identification of optimal compression options and alternatives.
- Milestones:** CO<sub>2</sub> transport workshop **TBD 2014**  
 Interim Report **TBD 2015**  
 Final Report **TBD 2016**
- Priority:** High

## Storage and Utilization

Geologic storage and monitoring will need to meet standards in order to assure their safety and effectiveness. Such standards will affect the design and operation of projects, as well as their financial viability. Regulations that set such standards have been implemented or proposed in a number of jurisdictions and “best practices” have been recommended based on prior research.

Injection of CO<sub>2</sub> for Enhanced Oil Recovery (EOR) has been practiced for decades and may be an early geologic storage application. EOR practices may be different from geologic storage, for example, in the recycling of CO<sub>2</sub>.

Considerable technical research has been conducted by geologists on the risks of geologic storage. Yet, from the perspective of a developer of a geologic storage project, the concerns are not limited to just physical impacts; the potential for financial liability is also a concern and the linkage between the two is often unclear.

The mandate of the CSLF Charter is being expanded from CCS to CCUS. This raises questions that need to be explored about what the opportunities are for utilization.

### [Action Plan T7: Storage and Monitoring for Commercial Projects](#)

- Responsibility:** Technical Group/New or Existing Task Force or Working Group
- Action:** The Technical Group will identify, review, and recommend standards for CO<sub>2</sub> storage and monitoring.
- Outcome:** Recommendations of standards for storage and monitoring of injected CO<sub>2</sub>. The application of such standards should inform CO<sub>2</sub> crediting mechanisms.
- Milestones:** Interim Report **TBD 2015**  
 Final Report **TBD 2016**
- Priority:** Very High

Action Plan T8: Technical Challenges for Converting CO<sub>2</sub> EOR Projects to CCS

- Responsibility:** Technical Group/New Task Force or Working Group
- Action:** The Technical Group will determine technical and economic factors that can affect Enhanced Oil Recovery (EOR) that are also used for geologic storage of CO<sub>2</sub>.
- Outcomes:** Identification and recommendation of permitting, monitoring, and reporting requirements for CO<sub>2</sub> EOR projects that apply for CO<sub>2</sub> credits.
- Milestones:** Interim Report **TBD 2014**  
Final Report **TBD 2015**
- Priority:** High

Action Plan T9: Risk and Liability

- Lead:** Risk Assessment Task Force (or participation in new joint Policy-Technical Task Force)
- Action:** The Technical Group will identify and assess links between technology-related risks and liability.
- Outcome:** Development of proposed guidelines for addressing long-term technology-related risks with respect to potential liabilities.
- Milestones:** Risk and liability workshops **TBD 2013-2014**  
Thematic report with proposed guidelines **TBD 2015**
- Priority:** Very High

Action Plan T10: CO<sub>2</sub> Utilization Options

- Responsibility:** Technical Group/New Task Force or Working Group
- Action:** The Technical Group will investigate CO<sub>2</sub> utilization options.
- Outcomes:** Identification of most economically attractive CO<sub>2</sub> utilization options.
- Milestones:** Interim Report **TBD 2013**  
Final Report **TBD 2014**
- Priority:** Very High

## Understanding the Impacts

Each component of CCS—capture, transport and geologic storage—has the potential to compete for valuable resources such as land, water and pore space with other uses, for example, hydrocarbon production or other water or land uses. What is the nature of this potential competition? Where does it occur? How can it be minimized?

### Action Plan T11: Competition of Geologic Storage with Production of Other Resources

<b>Responsibility:</b>	Technical Group/New Task Force or Working Group	
<b>Action:</b>	The Technical Group will examine criteria for assessing competing development priorities between CCS (particularly CO <sub>2</sub> storage) and other economic resources.	
<b>Outcomes:</b>	Identification and recommendation of criteria for determining relative economic viability of CO <sub>2</sub> storage sites.	
<b>Milestones:</b>	Interim Report Final Report	<b>TBD 2014</b> <b>TBD 2015</b>
<b>Priority:</b>	Very High	

## 5. SECRETARIAT STRATEGY AND ACTION PLANS

The CSLF Charter states that, “The principal coordinator of the CSLF’s communications and activities will be the CSLF Secretariat. The Secretariat will: (1) organize the meetings of the CSLF and its sub-groups, (2) arrange special activities such as teleconferences and workshops, (3) receive and forward new membership requests to the Policy Group, (4) coordinate communications with regard to CSLF activities and their status, (5) act as a clearing house of information for the CSLF, (6) maintain procedures for key functions that are approved by the Policy Group, and (7) perform such other tasks as the Policy Group directs. The focus of the Secretariat will be administrative. The Secretariat will not act on matters of substance except as specifically instructed by the Policy Group.”

Pursuant to this mandate, these responsibilities fall into three areas:

- CSLF Administration,
- Stakeholder Engagement, and
- Collaboration with Other International Organizations.

### CSLF Administration

This involves carrying out the administrative duties as set out by the CSLF Charter, as well as the administration of the CSLF Capacity Building Program.

#### Action Plan S1: CSLF Administration

**Responsibility:** CSLF Secretariat

**Action:** Conduct the day-to-day business of the CSLF.

**Outcome:** Administration of CSLF activities proceeds smoothly.

<b>Milestones:</b>	Support to and conduct of all CSLF meetings	<b>Ongoing</b>
	Support to Policy Group, Technical Groups and Task Force Chairs	<b>Ongoing</b>
	Coordination of activities	<b>Ongoing</b>
	Member communications	<b>Ongoing</b>
	Preparation of CSLF documents	<b>As needed</b>
	Membership applications	<b>As needed</b>
	Strategic Plan Implementation Report	<b>Quarterly</b>
	Administration of Capacity Building Fund	<b>Ongoing</b>
	Strategic planning coordination	<b>2011</b>
	Other duties as assigned by the Policy Group Chair	<b>As needed</b>

**Priority:** Very High

## Action Plan S2: Administration of CSLF Capacity Building Program

**Responsibility:** CSLF Secretariat

**Action:** Conduct day-to-day business of the CSLF Capacity Building Program.

**Outcome:** Progress is made building the capacity of CSLF Members

<b>Milestones:</b>	Conduct needs assessments	<i>As needed</i>
	Support project selection process	<i>As needed</i>
	Support meetings of the Governing Council	<i>As needed</i>
	Manage contractors on Capacity Building Projects	<i>As needed</i>
	Manage the CSLF Capacity Building Fund	<i>Ongoing</i>
	Financial Reports to the Policy Group	<i>Twice per year</i>

**Priority:** Very High

## Stakeholder Engagement

CSLF Members recognize that significant Stakeholder involvement in the CSLF process is critical to attaining its goals and objectives. Stakeholders have participated in the CSLF since its inception by serving on Task Forces, and by providing resources for CSLF activities and input into the CSLF decision-making process. To achieve the CSLF strategic goals, it is expected that Stakeholders will play an increasing role in supporting the activities of the CSLF by serving on Policy and Technical Task Forces and providing expert views on major issues. Delivering industrial-scale CCS projects world-wide requires a central role for industry within the government-industry partnerships necessary to deliver these projects. In support of this, the CSLF will seek to facilitate greater interaction between CSLF Members and industry stakeholders. Other types of stakeholders are also critical to public acceptance and technology advancement.

The G8/IEA/CSLF workshops are a benchmark for Stakeholder engagement; therefore, the CSLF will implement that style of process more broadly. The CSLF will more effectively engage and draw upon the expertise of Stakeholders. To this end, the CSLF will undertake the following:

1. Ensure effective and efficient communication with Stakeholders to promote greater participation in CSLF activities;
2. Make facilities available for Stakeholders to hold a forum at each annual CSLF meeting, including Ministerial meetings;
3. Stakeholders, including those from non-CSLF Member countries, will continue to be encouraged to attend, participate and contribute to all Policy Group and Technical Group, Task Force and Ministerial Meetings.
4. A Stakeholder contact will be identified for each CSLF Member.
5. CSLF Members will encourage meetings with Stakeholders in their constituencies to inform and discuss with them CSLF and CCS issues.
6. Collaboration will continue with the IEA and Global CCS Institute on a calendar of events to be posted on the CSLF website.

### Action Plan S3: Stakeholder Engagement

- Responsibility:** CSLF Secretariat/Policy Group
- Action:** The CSLF will more effectively engage and draw upon the expertise of Stakeholders.
- Outcome:** Greater Stakeholder participation and more robust CSLF products including wider acceptability and applicability.
- Milestones:**
- |  |                       |
|--|-----------------------|
| Make facilities available for Stakeholders forum at each annual CSLF meeting, including Ministerial.   | <b>Ongoing</b>        |
| Stakeholders invited to all Policy Group and Technical Group and Task Force Meetings.                  | <b>Ongoing</b>        |
| Stakeholder contact identified for each CSLF Member  | <b>1 January 2010</b> |
| Collaborate with the IEA and Global CCS Institute on a calendar of events to be posted on CSLF website | <b>Ongoing</b>        |
- Priority:** High

### Collaboration with other International Organizations

As noted earlier, a number of multilateral organizations now work to advance CCS and CCUS. Collaboration among these international organizations has the potential to improve the effectiveness of each and avoid duplication. The CSLF has a unique role internationally, which is as an organization of governments solely devoted to promoting CCUS globally, which gives it a unique perspective and enables it to work on a complementary basis with the other organizations.

The CSLF has collaborated with the IEA since the inception of the CSLF and with the Global CCS Institute since the inception of that organization. Other collaborations have taken place with the CCUS Action Group, the World Bank and the Asian Development Bank. Such collaborations will continue and be expanded.

### Action Plan: S4 International Collaboration

- Responsibility:** CSLF Secretariat
- Action:** The CSLF will continue a formal, long-term working relationship with the IEA and Global CCS Institute, World Bank and other international organizations involved in CCS. The Global CCS Institute and the IEA will be invited to all CSLF events.
- Outcome:** A collaborative agreement identifies the lead and supporting roles of each organization; that each organization ensures that the others are invited to important meetings; and that there is a consistent exchange of information, ideas and developments on CCS.
- Milestones:** Meet with the IEA and Global CCS Institute to ensure coordination and collaboration **Ongoing**

**Priority:** High

Action Plan S5: Providing Information on CCS in International Negotiations

**Responsibility:** CSLF Secretariat

**Action:** Support the Members in advocating the inclusion of CCS in the post-Kyoto framework for climate change by facilitating the exchange of information on CCUS before the UNFCCC and in other fora relevant to the status of CCUS methods as a recognized approach for mitigation of greenhouse gas emissions.

**Outcome:** Members are effective in advocating inclusion of CCS in the post-2012 agreement

**Milestones:** Respond as requested to requests of the CSLF Policy Group. **Ongoing**

**Priority:** High

## **Annex 1**

### **Communications Task Force Strategy and Activities**

#### **Summary**

As is evident in media coverage, high-level meetings, and public opinion, carbon capture and storage (CCS) is increasingly mentioned as a potential mitigation option for effectively reducing CO<sub>2</sub> emissions while contributing to the security of national energy supplies. Although this is a positive trend, the worldwide level of understanding about CCS, its technologies and potential is low to non-existent, emphasizing the importance of engaging opportunities for disseminating affirmative and useful information.

Studies indicate that exposure to information from experts increases stakeholder understanding and support for CCS technology. Even more importantly, the results also suggest that those who understand CCS tend to support its advancement. Ultimately, stakeholder communities can be potentially powerful advocates who can assist in communicating the benefits of CCS to strategic venues and media.

Through its significant role and mission in the international effort to minimize global CO<sub>2</sub> emissions and reduce the threat of potential climate change, the CSLF clearly should be in the forefront of efforts to educate stakeholders and constituent audiences about CCS technology. The organization's responsibility in this regard is articulated in the 2011 update of the CSLF Strategic Plan which, among its technical, political, and regulatory goals, includes the need to "address the barriers to public awareness and acceptance" and "engage stakeholders in the development and execution" of the plan's objectives.

In addressing these challenges, the Strategic Plan directs the CSLF to focus its communications and outreach efforts on the "global aspects of CCS as an important mitigation technology," since project acceptability will be highly dependent on local conditions that could differ greatly from location-to-location. A key to the CSLF successfully achieving this objective is an integrated and collaborative communications and outreach effort that effectively engages key stakeholders and audiences in a variety of ways with timely, interesting, and educational information.

In conveying the central message about CCS technology as a vital mitigation option, an effective and comprehensive outreach strategy and effort will also: Raise CSLF visibility and establish the organization as a credible source on CCS technologies and policies; Help extend public confidence in the viability of fossil fuel resources for meeting both increased future energy needs and concerns about CO<sub>2</sub>'s contribution to potential climate change; Promote efforts by the CSLF and its members to realize CCS's promise and potential.

An important point to note is the fact that the CSLF lacks a communications and outreach budget that would allow for a much more extensive and effective program. Therefore, the communications plan recommends activities aimed at marshalling the collective in-kind capabilities and existing communications vehicles of CSLF members and the Secretariat in a proactive manner in an attempt to bring about realization of the stated objectives.

## Objectives of the Communications and Outreach Plan

The primary goals of the activities suggested are to:

- Raise CSLF visibility and communicate important CSLF-related information;
- Engage key stakeholders and audiences with timely information in an integrated effort;
- Achieve outreach objectives as identified in the CSLF Strategic Plan.

## Key Components

To accomplish these goals, the communications plan suggests the organization and members use a variety of communications tools:

- Web Site – Continue to refine existing CSLF web site, build on strengths, continually improving functionality and content.
- Identifying and Deploying “Messengers” – Continue to identify “spokesperson” from each CSLF member nation.
- Creating Communications Vehicles – Develop new communications tools and materials and refine existing materials for the CSLF membership to help deliver consistent information and reinforce the CSLF identity.
- Maximizing Venue Use – Identifying on a country, regional, and international basis the most effective venues, meetings, and conferences for promoting CCS and the CSLF.
- Encouraging Media Coverage – Undertaking a proactive effort to engage trade and major media, locally, regionally, and internationally.
- Identify Strategic Partner Relationships – Create a list by members of potential “allies,” both nationally and regionally, who can be engaged to leverage CSLF communications efforts.
- Making Adjustments – Conducting regular reviews of CSLF outreach efforts; make adjustments when necessary.
- Coordinate with other CSLF Task Forces as appropriate on outreach activities.

## Key Activities

- Web Site Review/Updating
- Members Identify CSLF Spokespersons
- Communications Vehicles/Talking Points Preparation/Updating
- Communications Materials/Standard Speech Preparation/Updating
- Communications Materials/Power Point Preparation/Updating
- Identify Conference/Speaking Venues
- Media Initiatives/Develop Media Contact List
- Media Initiatives/Monitor CCS News Coverage
- Media Initiatives/Disseminating CSLF NewsAlerts
- Media Initiatives/Directing Media to Web Sites
- Media Initiatives/Creating Op-Eds
- Media Initiatives/Media Briefings
- Identify Strategic Partners
- Conduct Regular Reviews of Communications and Outreach Effort



## Active and Completed CSLF Recognized Projects

(as of September 2012)

### 1. Alberta Enhanced Coal-Bed Methane Recovery Project (*Completed*)

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

This pilot-scale project, located in Alberta, Canada, aimed at demonstrating, from both economic and environmental criteria, the overall feasibility of coal bed methane (CBM) production and simultaneous CO<sub>2</sub> 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<sub>2</sub> injection and storage on CBM production; assess economics; and monitor and trace the path of CO<sub>2</sub> 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<sub>2</sub> while still sequestering CO<sub>2</sub>, albeit in smaller quantities.

*Recognized by the CSLF at its Melbourne meeting, September 2004*

### 2. CANMET Energy Technology Centre (CETC) R&D Oxyfuel Combustion for CO<sub>2</sub> 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<sub>2</sub> capture. The goal of the project is to develop energy-efficient integrated multi-pollutant control, waste management and CO<sub>2</sub> 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*

### 3. 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<sub>2</sub> reduction, post-combustion capture, and CO<sub>2</sub> storage performance and risk assessment studies. The goal was to reduce the cost of post-combustion CO<sub>2</sub> capture and to develop and validate, in both public and private partnerships, all the innovative technologies needed to capture and store CO<sub>2</sub> 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*

### 4. CCS Belchatów Project

*Nominators: Poland (lead), European Commission, and United States*

This is a large-scale project, located in central Poland, which will demonstrate commercial-scale CO<sub>2</sub> capture, transport and storage at a new lignite-fired power plant unit. The project will demonstrate the full CCS value chain, including capture, transport, and safe geological storage of up to 1.8 million tonnes of CO<sub>2</sub> per year. Project components include identification of potential issues related to intellectual property,

storage site selection, permitting, facilities and pipeline construction, and public engagement activities. Success of this project will expedite commercialization of CCS for large-scale fossil fuel power generation.

*Recognized by the CSLF at its Warsaw meeting, October 2010*

## **5. CCS Rotterdam Project**

*Nominators: Netherlands (lead) and Germany*

This project will implement a large-scale “CO<sub>2</sub> Hub” for capture, transport, utilization, and storage of CO<sub>2</sub> in the Rotterdam metropolitan area. The project is part of the Rotterdam Climate Initiative (RCI), which has a goal of reducing Rotterdam’s CO<sub>2</sub> emissions by 50% by 2025 (as compared to 1990 levels). A “CO<sub>2</sub> cluster approach” will be utilized, with various point sources (e.g., CO<sub>2</sub> captured from power plants) connected via a hub / manifold arrangement to multiple storage sites such as depleted gas fields under the North Sea. This will reduce the costs for capture, transport and storage compared to individual CCS chains. The project will also work toward developing a policy and enabling framework for CCS in the region.

*Recognized by the CSLF at its London meeting, October 2009*

## **6. CGS Europe Project**

*Nominators: Netherlands (lead) and Germany*

This is a collaborative venture, involving 35 partners from participant countries in Europe, with extensive structured networking, knowledge transfer, and information exchange. A goal of the project is to create a durable network of experts in CO<sub>2</sub> geological storage and a centralized knowledge base which will provide an independent source of information for European and international stakeholders. The CGS Europe Project is intended to provide an information pathway toward large-scale implementation of CO<sub>2</sub> geological storage throughout Europe. This is intended to be a three-year project, starting in November 2011, and has received financial support from the European Commission’s 7th Framework Programme (FP7).

*Recognized by the CSLF at its Beijing meeting, September 2011*

## **7. China Coalbed Methane Technology/CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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*

## **8. CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> sources around the world, including power plants and other industrial processes. The ultimate goal of the entire project is to reduce the cost of CO<sub>2</sub> 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*

## **9. CO<sub>2</sub> Capture Project – Phase 3**

*Nominators: United Kingdom (lead) and United States*

This is a collaborative venture of seven partner companies (international oil and gas producers) plus the Electric Power Research Institute. The overall goals of the project are to increase technical and cost knowledge associated with CO<sub>2</sub> capture technologies, to reduce CO<sub>2</sub> capture costs by 20-30%, to quantify remaining assurance issues surrounding geological storage of CO<sub>2</sub>, and to validate cost-effectiveness of monitoring technologies. The project is comprised of four areas: CO<sub>2</sub> Capture; Storage Monitoring & Verification; Policy & Incentives; and Communications. A fifth activity, in support of these four teams, is Economic Modeling. This third phase of the project will include at least two field demonstrations of CO<sub>2</sub> capture technologies and a series of monitoring field trials in order to obtain a clearer understanding of how to monitor CO<sub>2</sub> in the subsurface. Third phase activities began in 2009 and are expected to continue into 2013. Financial support is being provided by project consortium members.

*Recognized by the CSLF at its Beijing meeting, September 2011*

## **10. CO<sub>2</sub>CRC Otway Project**

*Nominators: Australia (lead) and United States*

This is a pilot-scale project, located in southwestern Victoria, Australia, that involves transport and injection of approximately 100,000 tons of CO<sub>2</sub> over a two year period into a depleted natural gas well. Besides the operational aspects of processing, transport and injection of a CO<sub>2</sub>-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<sub>2</sub> 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<sub>2</sub> capture and storage (CCS) in Australia.

*Recognized by the CSLF at its Paris meeting, March 2007*

## **11. CO<sub>2</sub> Field Lab Project**

*Nominators: Norway (lead), France, and United Kingdom*

This is a pilot-scale project, located at Svelvik, Norway, which will investigate CO<sub>2</sub> leakage characteristics in a well-controlled and well-characterized permeable geological formation. Relatively small amounts of CO<sub>2</sub> will be injected to obtain underground distribution data that resemble leakage at different depths. The resulting underground CO<sub>2</sub> 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<sub>2</sub> storage safety by obtaining valuable knowledge about monitoring CO<sub>2</sub> migration and leakage. The outcomes from this project will help facilitate commercial deployment of CO<sub>2</sub> storage by providing the protocols for ensuring compliance with regulations, and

will help assure the public about the safety of CO<sub>2</sub> storage by demonstrating the performance of monitoring systems.

*Recognized by the CSLF at its Warsaw meeting, October 2010*

## **12. CO<sub>2</sub> GeoNet**

*Nominators: European Commission (lead) and United Kingdom*

This multifaceted project is focused on geologic storage options for CO<sub>2</sub> 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<sub>2</sub>, identification of knowledge gaps in the long-term geologic storage of CO<sub>2</sub>, 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*

## **13. CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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*

## **14. CO<sub>2</sub> STORE (Completed)**

*Nominators: Norway (lead) and European Commission*

This project, a follow-on to the Sleipner project, involved the monitoring of CO<sub>2</sub> migration (involving a seismic survey) in a saline formation beneath the North Sea and additional studies to gain further knowledge of geochemistry and dissolution processes. There were also several preliminary feasibility studies for additional geologic settings of future candidate project sites in Denmark, Germany, Norway, and the UK. The project was successful in developing sound scientific methodologies for the assessment, planning, and long-term monitoring of underground CO<sub>2</sub> storage, both onshore and offshore.

*Recognized by the CSLF at its Melbourne meeting, September 2004*

## **15. CO<sub>2</sub> Technology Centre Mongstad Project (formerly European CO<sub>2</sub> Technology Centre Mongstad Project)**

*Nominators: Norway (lead) and Netherlands*

This is a large-scale project (100,000 tonnes per year CO<sub>2</sub> capacity) that will establish a facility for parallel testing of amine-based and chilled ammonia CO<sub>2</sub> capture technologies from two flue gas sources with different CO<sub>2</sub> contents. The goal of the project is to reduce cost and technical, environmental, and financial risks related to large scale CO<sub>2</sub> capture, while allowing evaluation of equipment, materials, process configurations, different capture solvents, and different operating conditions. The project will result in validation of process and engineering design for full-scale application and will provide insight into other aspects such as thermodynamics, kinetics, engineering, materials of construction, and health / safety / environmental (HSE).

*Recognized by the CSLF at its London meeting, October 2009*

## **16. Demonstration of an Oxyfuel Combustion System (Completed)**

*Nominators: United Kingdom (lead) and France*

This project, located at Renfrew, Scotland, UK, will demonstrate oxyfuel technology on a full-scale 40-megawatt burner. The goal of the project is 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 will be used to develop advanced computer models of the oxyfuel combustion process, which will be utilized in the design of large oxyfuel boilers.

*Recognized by the CSLF at its London meeting, October 2009*

## **17. Dynamis (Completed)**

*Nominators: European Commission (lead), and Norway*

This was the first phase of the multifaceted European Hypogen program, which will result in the construction and operation of an advanced commercial-scale power plant with hydrogen production and CO<sub>2</sub> management. The overall aim is for operation and validation of the power plant during the 2012-2015 timeframe. The Dynamis project assessed the various options for large-scale hydrogen production while focusing on the technological, economic, and societal issues.

*Recognized by the CSLF at its Cape Town meeting, April 2008*

## **18. 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<sub>2</sub>/CO<sub>2</sub> 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<sub>2</sub> capture technologies (including O<sub>2</sub>/CO<sub>2</sub> 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*

## **19. 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<sub>2</sub> 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<sub>2</sub> injection and demonstrate that robust monitoring, verification, and accounting (MVA) of a brine-saturated CO<sub>2</sub> 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<sub>2</sub> 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*

## **20. Frio Project (*Completed*)**

*Nominators: United States (lead) and Australia*

This pilot-scale project demonstrated the process of CO<sub>2</sub> sequestration in an on-shore underground saline formation in Eastern Texas, USA. This location was ideal, as very large scale sequestration may be needed in the area to significantly offset anthropogenic CO<sub>2</sub> releases. The project involved injecting relatively small quantities of CO<sub>2</sub> into the formation and monitoring its movement for several years thereafter. The goals were to verify conceptual models of CO<sub>2</sub> 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<sub>2</sub> injection experiments.

*Recognized by the CSLF at its Melbourne meeting, September 2004*

## **21. Geologic CO<sub>2</sub> 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<sub>2</sub> storage in conjunction with commercial natural gas production. The goals of the project are to develop a detailed dataset on the performance of CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> re-injection and hydrocarbon production for long-term storage in oil and gas fields.

*Recognized by the CSLF at its Berlin meeting, September 2005*

## **22. Gorgon CO<sub>2</sub> Injection Project**

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

This is a large-scale project that will store approximately 120 million tonnes of CO<sub>2</sub> in a water-bearing sandstone formation two kilometers below Barrow Island, off the northwest coast of Australia. The CO<sub>2</sub> 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. The project has already progressed through its early development stages including site selection and appraisal, and is fully funded. Injection operations are expected to commence by the end of 2014.

*Recognized by the CSLF at its Warsaw meeting, October 2010*

## **23. IEA GHG Weyburn-Midale CO<sub>2</sub> Monitoring and Storage Project**

*Nominators: Canada and United States (leads) and Japan*

This is a large-scale project that will utilize CO<sub>2</sub> for enhanced oil recovery (EOR) at a Canadian oil field. The goal of the project is to determine the performance and undertake a thorough risk assessment of CO<sub>2</sub> storage in conjunction with its use in enhanced oil recovery. The work program will encompass four major technical themes of the project: geological integrity; wellbore injection and integrity; storage monitoring methods; and risk assessment and storage mechanisms. Results from these technical themes, when integrated with policy research, will result in a Best Practices Manual for future CO<sub>2</sub> Enhanced Oil Recovery projects.

*Recognized by the CSLF at its Melbourne meeting, September 2004*

#### **24. ITC CO<sub>2</sub> Capture with Chemical Solvents Project**

*Nominators: Canada (lead) and United States*

This is a pilot-scale project that will demonstrate CO<sub>2</sub> 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<sub>2</sub> from flue gas.

*Recognized by the CSLF at its Melbourne meeting, September 2004*

#### **25. Ketzin Test Site Project (formerly CO<sub>2</sub> SINK) (Completed)**

*Nominators: European Commission (lead) and Germany*

This is a pilot-scale project that tested and evaluated CO<sub>2</sub> 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<sub>2</sub>. The project was successful in advancing the understanding of the science and practical processes involved in underground storage of CO<sub>2</sub> and provided real case experience for use in development of future regulatory frameworks for geological storage of CO<sub>2</sub>.

*Recognized by the CSLF at its Melbourne meeting, September 2004*

#### **26. 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<sub>2</sub> 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<sub>2</sub> storage projects.

*Recognized by the CSLF at its London meeting, October 2009*

#### **27. 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<sub>2</sub> from an oil sands upgrading unit. The CO<sub>2</sub> 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*

#### **28. 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*

## **29. Regional Opportunities for CO<sub>2</sub> Capture and Storage in China (Completed)**

*Nominators: United States (lead) and China*

This project characterized the technical and economic potential of CO<sub>2</sub> capture and storage technologies in China. The goals were to compile key characteristics of large anthropogenic CO<sub>2</sub> 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<sub>2</sub> storage capacities in China. The project found 2,300 gigatons of potential CO<sub>2</sub> 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<sub>2</sub> emissions to the atmosphere.

*Recognized by the CSLF at its Berlin meeting, September 2005*

## **30. 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<sub>2</sub> capture from a coal-fueled power plant, pipeline transportation of the CO<sub>2</sub>, and offshore storage of the CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> Transportation Network.

*Recognized by the CSLF at its Beijing meeting, September 2011*

## **31. SaskPower Integrated CCS Demonstration Project at Boundary Dam Unit 3**

*Nominators: Canada (lead) and the United States*

This is a large-scale project, located in the southeastern corner of Saskatchewan Province in Canada, which will be the first application of full stream CO<sub>2</sub> recovery from flue gas of a 139 megawatt coal-fueled power plant unit. A major goal is to demonstrate that a post-combustion CO<sub>2</sub> 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<sub>2</sub> per year, which will be sold to oil producers for enhanced oil recovery (EOR) and injected into a deep saline aquifer. Commissioning of the reconfigured power plant unit

is expected by early 2014. The project has received financial support from the Government of Canada and the Saskatchewan Provincial Government, and SaskPower is investing additional funds for refurbishment of the power plant unit and installation of the CO<sub>2</sub> capture system.

*Recognized by the CSLF at its Beijing meeting, September 2011*

### **32. SECARB Early Test at Cranfield Project**

*Nominators: United States (lead) and Canada*

This is a large-scale project, located near Natchez, Mississippi, USA, which involves transport, injection, and monitoring of approximately one million tonnes of CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> capture, transportation via pipeline, and injection into a deep saline formation.

*Recognized by the CSLF at its Warsaw meeting, October 2010*

### **33. Zama Acid Gas EOR, CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> per year.

*Recognized by the CSLF at its Paris meeting, March 2007*

### **34. Zero Emission Porto Tolle Project (ZEPT)**

*Nominators: Italy (lead) and European Commission*

This is a large-scale project, located in northeastern Italy, which will demonstrate post-combustion CCS on 40% of the flue gas from one of the three 660 megawatt units of the existing Porto Tolle Power Plant (which is being converted from heavy oil fuel to coal). The goal of the project is to demonstrate industrial application of CO<sub>2</sub> capture and geological storage for the power sector at full commercial scale. The demonstration plant will be operated for an extended period (approx. 10 years) in order to fully demonstrate the technology on an industrial scale, clarify the real costs of CCS, and prove the retrofit option for high-efficiency coal fired units which will be built (or replaced) in the coming 10-15 years. Storage of approx. 1 million tonnes per year of CO<sub>2</sub> will take place in a deep saline aquifer beneath the seabed of the Adriatic Sea approx. 100 kilometers from the project site.

*Recognized by the CSLF at its Beijing meeting, September 2011*

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



# Strategic Plan Implementation Report

September 2012

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# Report from CSLF Secretariat

## 2011 CSLF Ministerial Meeting

The CSLF held its 4th CSLF Ministerial Meeting in Beijing, China on September 19-23, 2011. Over 400 people registered for this event, with the highlight being the Ministerial Conference on September 22. The first two days consisted of individual group and task force meetings, including the Projects Interaction and Review Team (PIRT), the Carbon Capture and Storage (CCS) in Academic Community Task Force, the Financing CCS Task Force, the Risk Assessment Task Force (RATF), the Task Force for Assessing Progress on Technical Issues Affecting CCS, the Capacity Building Task Force, and the Capacity Building Governing Council. The afternoon of the second day also included separate meetings of the Policy Group and Technical Group. Five new projects were approved for CSLF recognition:

- CO<sub>2</sub> Capture Project – Phase 3
- CGS Europe Project
- Rotterdam Opslag en Afvang Demonstratieproject (ROAD)
- SaskPower Integrated CCS Demonstration at Boundary Dam Unit 3
- Zero Emissions Porto Tolle (ZEPT)

This brings the total number of CSLF recognized projects to 34, including 24 active projects.

The morning of Wednesday, September 21, featured the Opening Ceremony of the 2011 CSLF Ministerial Meeting. Host country remarks were given by China's Vice Minister of Science and Technology Cao Jianlin. Policy Group Chair Charles McConnell, United States, delivered the Opening Statement. Afterwards, Vice Minister Cao, Policy Group Chair McConnell, and CSLF Secretariat Director Barbara McKee presented the CSLF Global Achievement Awards. Each of the three accomplished projects reached significant milestones with sustained operation demonstrating the capture, injection, and storage of several million tons of carbon dioxide (CO<sub>2</sub>). Recipients of the award were the In Salah CO<sub>2</sub> Storage Project, Algeria; the Sleipner CO<sub>2</sub> Project, North Sea; and the Weyburn-Midale CO<sub>2</sub> Project, Canada.

After the Opening Ceremony, the Policy Group and Technical Group reconvened for separate meetings during the morning. The afternoon activities included the Stakeholders Forum with exhibition. Peng Sizhen, Deputy Director General, the Administrative Centre for China's Agenda 21, Ministry of Science and Technology, China; and Jeff Chapman, Chief Executive Officer, Carbon Capture and Storage Association, United Kingdom, served as the forum co-chairs. Sun Chengyong, Counsellor, Department of Social Development, Ministry of Science & Technology, China; provided a keynote address and welcoming remarks. Philippe Joubert, Deputy Chief Executive Officer, Alstom, France; provided the second keynote address. Topics for the two sessions during the Stakeholders Forum were "State-of-the-Art CCS Technologies" and "What Will Make CCS Attractive to Investors?"

Thursday, September 22, featured the Ministerial Conference. Wan Gang, Minister of Science and Technology, China; and Xie Zhenhua, Vice Chairman of the National Development and Reform Commission, China; provided the welcoming and remarks on carbon capture, utilization and storage (CCUS) in China. Martin Ferguson, Minister for Resources, Energy and Tourism, Australia; Steven Chu, Secretary of Energy, United States;

Ola Borten Moe, Minister of Petroleum and Energy, Norway; and Chris Huhne, Secretary of State of Energy & Climate Change, United Kingdom; served as moderators or keynote speakers for various aspects of the meeting. As a result of the meeting, the ministers and heads of delegation released the Communiqué that endorsed CCUS technologies as a key component of international plans to combat climate change. The Communiqué also stressed the urgency with which the number of large CCUS demonstrations must be increased to ensure deployment of CCUS commercially by the end of the decade. Later that afternoon, Steven Chu, Secretary of Energy, United States; Wan Gang, Minister of Science and Technology, China; and Xie Zhenhua, Vice Chairman of the National Development and Reform Commission, China; provided public statements at the Press Conference. To read the Communiqué, please visit the following address:

[http://www.cslforum.org/pressroom/publications/beijing\\_communique\\_final.pdf](http://www.cslforum.org/pressroom/publications/beijing_communique_final.pdf)

On the final day of the meeting, the Policy Group and Technical Group met during the morning for the Joint Meeting of the CSLF Policy and Technical Group. During the afternoon, participants attended a technical site visit to the Huaneng Group Beijing Gaobeidian, a 3,000 tons-per-annum CO<sub>2</sub> capture pilot project.

Additional information about the meeting is online at the CSLF website:

<http://www.cslforum.org/meetings/beijing2011/index.html>

## **2012 CSLF Technical Group Meeting and CO<sub>2</sub> Capture Workshop**

The CSLF Technical Group met in Bergen, Norway on June 11-14, 2012. The meeting featured several presentations from Norwegian experts on the status of CCUS in their country, formation of four new task forces for work on various aspects of the new Technical Group Action Plan, and formation of a new working group to shepherd the development of the 2013 CSLF Technology Roadmap. Three new projects were recommended to the Policy Group for CSLF recognition:

- Illinois Basin – Decatur Project
- Illinois Industrial Carbon Capture and Storage Project
- Air Products CO<sub>2</sub> Capture from Hydrogen Facility Project

Additional information about the meeting is online at the CSLF website:

<http://cslforum.org/meetings/bergen2012/index.html>

A one-day technology workshop on CO<sub>2</sub> Capture was held on the final day of the Technical Group meeting, and featured presentations and interactive discussions with representatives from nine different CSLF-recognized projects. Approximately 40 people were in attendance. Session 1 of the workshop, “Scaling Up Carbon Capture for Commercial Deployment”, identified and described possible issues and other considerations for CO<sub>2</sub> capture in commercial-scale projects, such as identifying and understanding the scale-up risks of CO<sub>2</sub> capture processes. Session 2, “Strategies and Technologies for Carbon Capture Cost Reduction”, explored possible strategies and other considerations that can reduce the cost for CO<sub>2</sub> capture at commercial scale. Presentations from the CSLF Technical Workshop on Project Integration are available at the following link:

[http://www.cslforum.org/meetings/workshops/technical\\_bergen2012.html](http://www.cslforum.org/meetings/workshops/technical_bergen2012.html)

## **CSLF Risk and Liability Workshop**

A Workshop on Risk and Liability of Geologic Storage of CO<sub>2</sub> was held in Paris, France on July 10-11, 2012. The purpose of this workshop was to improve the understanding of geological risks associated with CO<sub>2</sub> storage and their relationship to financial liabilities. This information is needed by governments to make decisions on liability management frameworks and by industry to make investment and operating decisions. The workshop also discussed how risk and liability information can be communicated effectively.

Session 1 of the workshop featured talks by senior representatives of the three sponsoring organizations, who defined the broader issues and related those to the overall context of CCUS deployment. Session 2 addressed how geologic risks are measured by geologists and geological engineers. Several presentations addressed how geological risks are estimated in different regions, the current state of knowledge about the risks of geologic storage, and how these risks vary by region. Session 3 addressed business risks and potential liabilities, how these are evaluated for business decisions and what this means to the different industries. Session 4 considered liability for geologic storage, how risks are valued and how the industry insurance and banking sectors address liabilities. Session 5 addressed government policy, the issues encountered by governments in addressing liability and their approaches to risk and liability. Session 6 addressed what will make the public be and feel safe and comfortable with CCUS and also what will make investors comfortable.

## **CSLF Hosts Technical Workshop on Project Integration with Global CCS Institute**

As a part of both the CSLF's and Global CCS Institute's focus on assisting CCS projects through knowledge sharing, a one-day workshop was organized to share experiences on CCS project integration and to identify priority integration topics that need further attention to facilitate CCS project development and deployment. The workshop was held in London, United Kingdom on November 3, 2011.

Approximately 50 people were in attendance, which allowed for open discussions on a range of technical topics related to CCS project integration, including heat integration, plant operability, environmental control, CO<sub>2</sub> specifications, and scale-up challenges. Interactive discussions between workshop participants also delved into the opportunities and challenges associated with integrating the CCS chain from a commercial and management perspective. Insights were presented on the timing of storage site characterization and issues associated with balancing transportation systems for CCS.

The open panel discussions were fed by presentations from leading projects with experience on key integration themes. Presentations from the CSLF Technical Workshop on Project Integration are available at the following link:

[http://www.cslforum.org/meetings/workshops/technical\\_london2011.html](http://www.cslforum.org/meetings/workshops/technical_london2011.html)

## **Financing CCS Roundtable held in Paris**

On January 20, 2012, the CSLF Financing CCS Task Force co-sponsored a roundtable discussion with the Global CCS Institute and the Societe Generale Corporate and Investment Banking in Paris, France. The discussion was titled “Commercial and Financial Structuring of Industrial Scale Projects with CCS, What Will it Take to Turn Ambition into Reality.” The meeting discussed how the first of the planned large-scale CCS projects (i.e., the “lighthouse” projects that are intended to demonstrate CCS at commercial scale) are having great difficulty achieving financing due to a perceived risk. Integration risk is a major concern. These first-of-a-kind projects are not so much meant to demonstrate individual technologies at a large scale as to demonstrate their integration. In addition, the inclusion of enhanced oil recovery (EOR) where possible, helps alleviate some of the risk due to the added revenue stream from the sale of CO<sub>2</sub>. The meeting concluded that at least ten “lighthouse” projects are needed to help reduce or remove risk and its resulting cost before commercialization of CCS is truly possible. As a result of this risk, no “lighthouse” project can be reasonably expected to go forward without substantial governmental support, either direct and/or from incentives, to close financing gaps.

## **CSLF Sponsors South African CCS Week**

From October 24-28, 2011, the CSLF sponsored the second South African CCS Week. The week was organized by the South African Centre for Carbon Capture and Storage (SACCCS) and South Africa’s Department of Energy. The meeting was paid in part with funds from the CSLF Capacity Building Governing Council. South African CCS Week included a two-day CCS conference focused on currently underway CCS activities in South Africa and the southern Africa region. South Africa’s Department of Energy Director-General, Ms. Nelisiwe Magubane, provided the welcoming remarks.

Four technical workshops were also included during South African CCS Week. Workshop topics included CO<sub>2</sub> injection projects, CCS legal and regulatory frameworks, CCS risk assessment, and CCS public engagement. One of the many highlights of South African CCS Week included the South African Department of Energy announcing the formation of a CCS Interdepartmental Task Team to develop a legal and regulatory framework for CCS in South Africa.

## **CSLF Capacity Building Fund sponsors Capacity Building Workshops in Mexico City**

In March 2012, two Capacity Building Workshops were held in Mexico City that were financially supported by the CSLF Capacity Building Fund. These workshops were organized by the CSLF, Mexico’s Institute of Engineering (UNAM), and Mexico’s National Autonomous University. This was an extended event, staged over two weeks, with the first week centered on geologic storage of CO<sub>2</sub> and the second week focused on CO<sub>2</sub> capture.

## **CSLF Capacity Building Fund sponsors Capacity Building Courses in Brazil**

As part of the CSLF Capacity Building Program, Brazil hosted a basic course from July 30 – August 3, 2012 at the Pontifical Catholic University of Rio Grande do Sul in Porto Alegre. As the first of four planned courses in Brazil to focus on CCS, this course was titled “Understanding Carbon Capture and Storage,” and was made possible through the CSLF Capacity Building funds. The event featured five days of presentations and discussions from global experts, including members from the Center of Excellence in Research and Innovation in Petroleum, Mineral Resources and Carbon Storage (CEPAC), Petrobras, and the CSLF Secretariat.

### **Public Outreach**

On January 19, 2012, the CSLF issued its latest *inFocus* paper entitled “What is Capacity Building?” Capacity building is the collective activities and efforts to create the information, tools, skills, expertise and institutions required to implement CCUS demonstrations and move them rapidly into commercial operation, particularly in emerging economies. To view this paper and learn more about capacity building, please visit the following website:  
[http://www.cslforum.org/publications/documents/cslf\\_infocus\\_whatiscapacity\\_building.pdf](http://www.cslforum.org/publications/documents/cslf_infocus_whatiscapacity_building.pdf)

# Report from the CSLF Stakeholders Autumn 2012

## *The South African Centre for Carbon Capture and Storage (SACCCS) South Africa*

Since the launch of the Atlas on Geological Storage of Carbon Dioxide in South Africa during September 2010, which indicated viable storage potential, work has proceeded on the pre-feasibility for the Test Injection scheduled for 2017. Projects currently underway include:

- Scoping Study for Test Injection
- Regulatory Requirements for Test Injection
- Zululand Basin Storage Potential
- Algoa Basin Storage Potential
- Geological Modelling of Storage Sites capacity building
- Financial Opportunities for CCS Test Injection in South Africa
- Public Outreach Determination
- Definition of “Capture Readiness” Determination
- Techno-Economic Study of CCS in South Africa
- Collateral Benefits – Job Creation/preservation, industry development
- The Department of Energy: Developing a Carbon Capture and Storage Regulatory Framework
- Participation in the COCATE Project to address inter alia transport of carbon dioxide

During May, 2012, the South African Government Cabinet endorsed the South African CCS Road Map.

Other CCS capacity building activities in South Africa include:

- Four post-graduate bursaries
- Post-primary Schools Science Expo
- CCS Course run by the University of Witwatersrand with NTNU Norway
- COP17 stand that was visited by the South African President and Minister of Energy.

\* \* \* \* \*

***Gorgon Project  
Chevron Australia Pty Ltd.  
Perth, Australia***

The project has progressed through its early development stages including site selection, site appraisal, facilities front end engineering and design and has obtained high level approvals including environmental approvals and approval to dispose of carbon dioxide by underground injection. The project is fully funded and construction has commenced.

The Gorgon Project is operated by an Australian subsidiary of Chevron and is a joint venture of the Australian subsidiaries of Chevron (approximately 47 percent), ExxonMobil (25 percent) and Shell (25 percent), Osaka Gas (1.25 percent), Tokyo Gas (one percent) and Chubu Electric Power (0.417 percent).

Achievements as of July 2012 include:

- The Gorgon Project remains on schedule for first gas in 2014. June 2012 marked 30 months of construction on Barrow Island and work continues to focus on constructing accommodation, site preparation and logistics activities.
- Dredging on the project has progressed well and is nearing completion.
- A Horizontal Direction Drilling program, which will bring the feed gas pipelines onto Barrow beneath an undisturbed shoreline, commenced in April 2011.
- More than \$17 billion has already been committed to Australia industry with more than 9,000 jobs created. Over the construction period about \$20 billion will flow to Australian industry.
- From the commencement of the Gorgon Project in September 2009, quarantine screening has been completed on more than 180,000 passengers and over 660,000 tonnes of freight. In addition, more than 26,000 personnel have received quarantine training specific to their role. One hundred and thirty audits have been completed to ensure contractors are meeting quarantine obligations and more than 200 quarantine compliant vessels successfully mobilised. The on-island workforce is steadily increasing with approximately 4,000 people. At peak construction around 5,000 will be housed on Barrow Island.

For more details on the latest Project news visit <http://www.chevronaustralia.com>

\* \* \* \* \*

*SEUCO*  
*School of Earth Sciences*  
*Kitui*  
*Kenya*

## **Potential for CO<sub>2</sub> geologic sequestration in Kenya**

Kenya's Vision 2030 is a national long-term development blue-print to create a globally competitive and prosperous nation with a high quality of life by 2030. The aim is to transform Kenya into a newly industrialized middle-income country providing a high quality of life to all its citizens by 2030 in a clean and secure environment. Kenya acknowledges that this vision will necessarily involve an increase in carbon dioxide (CO<sub>2</sub>) emissions, particularly when taking into account newly discovered coal resources at Mui Basin and potential oil deposit in Ngamia<sup>1</sup> located within the Anza Basin in Turrkana. Taking future emissions and current industrial and power generation point sources into account, Kenya wishes to explore the potential for Carbon Capture and Geologic Storage (CCS) locally.

The 17th Conference of the Parties (COP 17) to the United Nations Framework Convention on Climate Change (UNFCCC) and CMP (The ultimate decision making body of the Kyoto Protocol) adopted the modalities and procedures for carbon dioxide capture and storage in geological formations (CCS) as clean development mechanism (CDM) project activities, as contained in decision CMP 7 in 2011. The CDM Executive Board recently established the first CCS Working Group and as such, future CCS projects in Kenya registered under the

The Kenyan Ministries of Energy and Environment, the Kenya National Council for Science and Technology (NCST), the University of Nairobi and South Eastern University, the Nottingham Centre for Carbon Capture and Storage (NCCCS) and the Global CCS Institute wish to undertake a project that will consider the potential for the application of carbon capture storage (CCS) in Kenya.

A key part of this project is the development for a CCS Atlas of Kenya (the Atlas). The Atlas shall provide an effective and communicative tool for Kenyan decision makers as well as for the general public, media and energy agencies. The Atlas shall also serve to initiate a transnational dialogue regarding transport and storage of CO<sub>2</sub> especially within the East African Community and the Sub-Saharan region in general.

The Australian, British and Chinese Oil Exploration companies that have obtained data, on the Kenyan Government's behalf, within specific hydrocarbons exploration blocks in the Kenya's sedimentary terrain including the continental shelves and offshore the West Indian Ocean (Kenya's Coast line).

\* \* \* \* \*

*Alberta Energy*  
*The Government of Alberta (GoA)*  
*Canada*

- In April 2011, Alberta passed the *Carbon Sequestration Tenure Regulation*, which addresses three main components of tenure for CCS:
- Operators are now allowed to evaluate a potential storage site to investigate the geology and determine the adequacy and effectiveness of the site.
  1. Operators are now allowed to obtain leases to enable commercial-scale sequestration at suitable storage sites.
  2. The Province now requires a monitoring, measurement and verification plan and a closure plan that is to be approved in order for an operator to obtain tenure.
- Starting in March 2011, Alberta Energy, in conjunction with national and international stakeholders, initiated a Regulatory Framework Assessment to ensure that Alberta's CCS regulatory framework is world class. This effort is necessary to map out the regulatory process for large-scale CCS activity, to ensure there is no regulatory overlap, and to assure government and the public that CCS will be conducted in a safe and efficient manner. The Regulatory Framework Assessment is a collaborative project involving local and international experts from government, industry, non-governmental and academia. Issue specific Working Groups have developed recommendations to refine and guide legislation, regulations and the regulatory process for CCS. The Assessment is nearing completion, and a final report is planned to be delivered to the Government of Alberta in late-2012.
- To increase public awareness of CCS and its benefits to Albertans, the Government of Alberta undertook a public education and outreach campaign in October and November of 2011. The campaign provided accurate information to the public via newspaper inserts, television commercials based on three themes: CCS, enhanced oil recovery and climate change, and a new website ([www.SolutionsStartHere.com](http://www.SolutionsStartHere.com)).
- The Government of Alberta has committed to a major investment in CCS. Under the province's CCS funding program, three commercial scale CCS projects have been selected and final funding agreements have been signed for over \$1.5 billion (Cdn) over the next 15 years. These three fully integrated CCS projects will reduce carbon dioxide (CO<sub>2</sub>) emissions from the oil sands, electricity and value-added sectors by four million tonnes per year starting in 2015:
- Alberta Carbon Trunk Line (ACTL): The project is a new 240-kilometer CO<sub>2</sub> pipeline that will transport CO<sub>2</sub> captured from fertilizer and bitumen upgrader facilities to enhanced oil recovery (EOR) projects located in central Alberta. The

capacity of the pipeline will be approximately 14 million tonnes per year. The funding agreement was signed in February 2011.

- Quest: The project will capture approximately 1.2 million tonnes of CO<sub>2</sub> per year from a bitumen upgrader and store it underground in a deep saline aquifer. It is a fully integrated CCS project involving capture, pipeline transportation and storage. The funding agreement was signed in June 2011. The Quest project received final regulatory approvals in the summer of 2012. On September 5<sup>th</sup>, 2012, Royal Dutch Shell and its partners formally announced that they will proceed with the Quest project, with operations scheduled to begin in 2015.
- Swan Hills: The project is an integrated CCS project that will capture, transport and store 1.3 million tonnes of CO<sub>2</sub> per year. The project will build an in-situ coal gasification (ISCG) facility that will tap an un-mineable coal seam 1,400 metres below the surface. The coal will be gasified underground to produce CO<sub>2</sub> and hydrogen and the CO<sub>2</sub> will be separated, captured, and transported for use in EOR in the area and the hydrogen will be used to generate 300 megawatts of base-load electricity generation. The funding agreement was signed in July 2011.
- Project Pioneer: Was one of the four original CCS projects announced under Alberta's CCS funding program. In April 2012, TransAlta Corporation announced the cancellation of Project Pioneer, citing an insufficient market for carbon sales and the current price of emission reductions as the main barriers that prevented the project from proceeding. The cancellation of Project Pioneer in no way changes the Government of Alberta's commitment to CCS. The Government's investment in the three active projects, in excess of \$1.5 billion (Cdn), continues to be an unparalleled investment in CCS for a jurisdiction of Alberta's size.
- Knowledge sharing is a significant part of Alberta's CCS funding agreements. The Government of Alberta is committed to the public dissemination of the learnings and knowledge about CCS developed through the three projects to advance the development of other CCS projects in Alberta, and around the world. The first summary and detailed reports have been submitted by the proponents to the Government of Alberta, and a review of these documents for completeness is currently being undertaken.
- The International Organization for Standardization (ISO) is developing a standard for carbon capture and storage. This worked kicked-off in June, 2012. The Assistant Deputy Minister of the Electricity, Alternative Energy and Carbon Capture and Storage Division of Alberta Energy, Sandra Locke, has been appointed as the Chair of the ISO technical committee for the development of the CCS standard.

\* \* \* \* \*

*Rio Tinto*  
*Brisbane*  
*Australia*

Rio Tinto has announced AU\$6M in sponsorship over three years for the CO2CRC and the new Peter Cook Centre for CCS research. The funds, which are in addition to Rio Tinto's normal CO2CRC membership contribution, will be used to support operational, maintenance and other overhead costs at the Otway facility and Peter Cook Centre.

\* \* \* \* \*

**Task Force on Communications**  
 CSLF Task Force Strategic Implementation Report  
 September 2012

**1. Task Force Members**

- Australia – Margaret Sewell
- European Commission – Marisa Atienza Morales
- Mexico – José Miguel González Santaló
- Norway – Tone Skogen
- United Kingdom – Jonathan Hood
- United States – John Grasser (Chair)

**2. Purpose of Task Force**

Implement a communications strategy to raise the profile of the CSLF and CCUS.

**3. Milestones**

- Developed an overall CSLF communications plan/outreach strategy;
- Rebuilt the CSLF web so as to have a first-rate site and a communications tool available to help promote the organization;
- Redeveloped the CSLF information kit;
- Established a CSLF daily clipping service to all members;
- Redesigned CSLF exhibit with new graphics to mirror web page;
- Developed CSLF web page linking policy;
- Developed CSLF conference sponsorship policy;
- Reviewed and updated all CSLF materials for media and public handout, including the full set of *InFocus* message papers;
- Completed update of CSLF core speech for member use;
- Completed new stakeholder audience speech for member use;
- Completed update of CSLF power point presentation for member use;
- Completed update of DVDs containing CSLF outreach materials;
- Completed new *InFocus* paper: *What is Carbon Utilization*;
- Completed new *InFocus* paper: *What is Capacity Building*;
- Completed new *InFocus* paper: *CCUS: Legal and Regulatory Challenges*;
- Continued liaison with the GCCSI and IEA Clean Coal Centre.

**4. Status**

The Task Force continues to review all previously prepared outreach materials so as to insure all information and data is current. The CSLF core speech and power point have recently been revised and updated. A new general speech for stakeholder audiences also has been developed. The Task Force continues to review current and possible new tools and avenues for improving the dissemination of CSLF messages, as well as reaching out to new partners for collaboration.

**Projects Interaction and Review Team (PIRT)**  
 CSLF Task Force Strategic Implementation Report  
 September 2012

**1. Task Force Members**

The PIRT consists of:

- A core group comprising Members of the Technical Group, or as nominated by a CSLF Member country. Current membership consists of representatives from:
 

Australia	Clinton Foster (Chair), Richard Aldous
Canada	Stefan Bachu
Denmark	Flemming Ole Rasmussen
European Commission	Jeroen Schuppers
France	Didier Bonijoly
Germany	Jürgen-Friedrich Hake
Japan	Ryo Kubo
Mexico	José Miguel González Santaló
Netherlands	Paul Ramsak
Norway	Trygve Riis
Saudi Arabia	Khalid Abuleif, Abdulmuhsen Alsunaid
South Africa	Tony Surridge
UK	Philip Sharman
USA	Darren Mollot
Global CCS Institute	Klaas van Alphen

During the period of this report the PIRT Chair resides with Australia.

- An *ad hoc* group of Stakeholders comprising representatives from CSLF-recognized projects.

**2. Purpose of Task Force**

The PIRT has the following functions:

- Assess projects proposed for recognition by the CSLF in accordance with the project selection criteria developed by the Technical Group and approved by the Policy Group. 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, and gaps, providing feed back to the Technical Group
- Provide input for further revisions of the CSLF Technology Roadmap (TRM).
- Identify technical, economic, environmental and other issues where it would be appropriate to have CSLF recognized projects.
- Foster enhanced international collaboration for CSLF projects, both within individual projects (e.g. expanding partnership to entities from other CSLF Members) and between different projects addressing similar issues.
- 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 projects, delegates, and stakeholders and provide feedback to the CSLF.
- Perform other such tasks which may be assigned to it by the CSLF Technical Group

### 3. Milestones

Near term (next 6 months)

- Input into the new Task Forces recognized at the Beijing CSLF Ministerial meeting and further developed at the Bergen Technical Group meeting.
- Reach agreement on emendations to simplify the *CSLF Gaps Analysis Checklist*, which accompanies the CSLF Project Submission Form.

Long term (next >18 months)

- Contribute to the next major revision of the CSLF Technology Road Map, scheduled for 2013. The PIRT Chair joins other Task Force Chairs as part of the Steering Group for the new Technology Road Map.
- Continue to assess projects that are submitted for recognition by the CSLF
- Work with the Technical Group, to continue to recognize opportunities for Technical Workshops, planning for at least one per year. These are effectively opportunistic, with respect to scheduling, location and topics of interest, based on collaboration or coordination with other CCS agencies and meetings.

### 4. Status

- At the Bergen meeting, three projects were recommended to Technical Group for submission to Policy Group for recognition as CSLF Projects
  - Illinois Basin Decatur Project
  - Illinois Industrial Carbon Capture and Storage Project
  - Air Products CO<sub>2</sub> Capture from Hydrogen Facility Project.
- The Draft report of the Task Force to *Assess the Technical Issues Affecting CCS* was submitted at the Bergen meeting: the outcomes will inform the new TRM and newly formed task forces.
- Governance .  
Continue to monitor CSLF- recognized projects: using four official classifications; *Completed, Active, Inactive, and Withdrawn by Sponsor* (the last category can only be applied upon formal notification by the project proponents, and not as a CSLF initiative).

**CCS Belchatów Project**  
CSLF Project Status Report  
September 2012

### 1. Project Location

The Belchatów CCS Project is located in Poland, in the Łódź province (in the center of Poland), Rogowiec village, 180 km south-west of Warsaw – Poland’s capital city.

The Belchatów CCS installation will be integrated into 858MW power unit being operated within the area mentioned above.

Initially three potential storage sites have been identified whereof one has been selected at the beginning of February 2012 for the II phase of storage component i.e. site characterization. The site selected for further geological examination is Wojszyce structure near Kutno town, about 115 km from Belchatów.

A procedure aiming at selection of contractor for preparatory works for the CO<sub>2</sub> transport pipeline construction started in February 2012. One of the tasks in scope of these works is pipeline routing determination.

### 2. Project Lead

- **Project Manager:**  
Marzena Gurgul  
CCS Project Director  
Phone: +48 44 735 4324  
Fax: +48 44 735 4060
- **Project Contact Person:**  
Artur Walentek  
CCS Specialist  
[artur.walentek@gkpge.pl](mailto:artur.walentek@gkpge.pl)  
Phone: +48 44 735 10 56  
Fax: +48 44 735 41 40

### 3. Project Objectives

The project’s objective is to complete the following CCS components:

- CCP plant
  - amine based post combustion CO<sub>2</sub> capture process
  - equivalent power of 260MWe
  - capture efficiency at least 85%
  - capture rate of 1.8 Mtpa (design value)
- CO<sub>2</sub> transport
  - pipeline transport of captured CO<sub>2</sub> in super critical conditions over a distance of about 141km in the Łódź Province
- CO<sub>2</sub> storage
  - CO<sub>2</sub> storage in deep saline aquifers

### 4. Recent Milestones

- Basic engineering (FEED study) for the capture component launched in November 2009 is completed.
- Building permit for the capture component obtained – February 2010.
- Feasibility study for the transport component completed.
- Geological storage site selection process launched. A potential storage site selected at

the beginning of February 2012 for site characterization.

- Procedure aiming at selection of contractor for preparatory works for the CO<sub>2</sub> transport pipeline construction is launched.

## 5. Status

- A Comprehensive Environmental Impact Assessment Study for the entire CCS installation has been prepared. This study demonstrated enough information to obtain “environmental decision” for CCP which was issued by a relevant authority on 11 December 2009.
- In terms of the capture component, a comprehensive FEED study has been carried out in the years 2009-2011. The timing of the FEED works was developed to allow preparation of documentation required to support the permitting process aiming at obtaining the CCP building permit. The latter was issued and got validated in February 2010.
- In 2009 three geological structures were identified for potential storage of the CO<sub>2</sub> leaving the CCP, all of them in the Łódzkie voivodeship, from c.a. 45 to 115km away from the CCP.
- A feasibility study for the transport component was completed in 2009 wherein a preliminary routing for three pipelines to the three considered storage sites was determined.
- At the beginning of 2012, following comprehensive geological works, analyses and examinations carried out in 2009-2011 and based on the experts’ recommendation Wojszyce structure was selected as most appropriate from geological point of view for continuation of geological works. The works will be done to get a detailed characterization of the site and thereby to confirm its suitability for safe CO<sub>2</sub> geological storage in industrial scale.
- Permitting activities for the transport component have been started; relevant EIA will be prepared in the scope of the preparatory works for the transport pipeline construction commenced shortly after the selection of Wojszyce site for the site characterization.
- On 5th May 2010 PGE GiEK S.A. signed Grant Agreement with European Commission and was awarded the amount of €180 million within the framework of European Energy Programme for Recovery.
- In addition to the €180 million grant being the subject of the Grant Agreement, PGE GiEK S.A. is seeking additional funding from national sources, New Entrants Reserve (NER) from the EU Emissions Trading System and Norwegian Financial Mechanism. On 9<sup>th</sup> February 2011 PGE GiEK S.A. submitted the NER300 application to the Ministry of Economy. In addition, PGE GiEK S.A. intends to invest own equity.
- PGE GiEK S.A. and its contractors recognise the importance of widespread commercialization of the developed technologies and participate in knowledge sharing activities organized by European Commission.
- PGE GiEK SA regularly publishes updates concerning its public awareness campaign on the following website: [http://www.pgegiiek.pl/index.php/category/events\\_ccs/](http://www.pgegiiek.pl/index.php/category/events_ccs/) (information in Polish only).
- Project’s website: <http://www.pgegiiek.pl/index.php/ccs/instalacja-demonstracyjna-ccs/> (website in Polish) and <http://www.pgegiiek.pl/index.php/ccs/ccs-demonstration-plant/> (website in English)

**CCS Rotterdam Project**  
 CSLF Project Status Report  
 September 2012

<b>1. Project Location</b>
Rotterdam, The Netherlands
<b>2. Project Lead</b>
<ul style="list-style-type: none"> <li>• Maarten de Hoog (<a href="mailto:maarten.dehoog@dcmr.nl">maarten.dehoog@dcmr.nl</a>)</li> <li>• Hans Knippels (<a href="mailto:hans.knippels@dcmr.nl">hans.knippels@dcmr.nl</a>)</li> </ul>
<b>3. Project Objectives</b>
<ul style="list-style-type: none"> <li>• Development of CCS in the greater Rotterdam area (Port of Rotterdam)</li> <li>• 2016 annual storage of 3 Mton CO<sub>2</sub> (postponement of FID ROAD makes meeting this target less likely)</li> <li>• 2025 annual storage of 17,5 Mton CO<sub>2</sub></li> </ul>
<b>4. Recent Milestones</b>
<ul style="list-style-type: none"> <li>• Strategic Position Paper Port of Rotterdam: “Port of Rotterdam CO<sub>2</sub> hub, crucial stepping stone towards sustainable growth.”</li> <li>• Publication CO<sub>2</sub> capture and Storage in Rotterdam, a network approach, May 2011.</li> <li>• Due diligence of several (three) possible CO<sub>2</sub> storage locations on Dutch Continental Shelf has been performed. Further detailed analysis is performed to have clarity on suitability storage locations.</li> <li>• Rotterdam CCS Cluster Project, Case Study on ‘lessons learnt’. Research carried out in commission of the Rotterdam Climate Initiative (= RCI) with funding from the Global CCS Institute.</li> </ul>
<b>5. Status</b>
<ul style="list-style-type: none"> <li>• EU-EEPR funding for the EON/Electrabel project. (ROAD) CCS demonstration plant of 250 MW size at the new EON coal fired power plant. Final Investment Decision has been postponed to October 2012.</li> <li>• NER300 project, Green hydrogen production by Air Liquide. Final selection of projects due end 2012.</li> <li>• Consortium (CINTRA) Development of the shipping business case, participants, Anthony Veder, Gasunie, VOPAK and Air Liquide for development of CO<sub>2</sub> terminal.</li> </ul>

**CGS Europe**  
CSLF Project Status Report  
August 2012

<b>1. Project Location</b>
All of Europe
<b>2. Project Lead</b>
<ul style="list-style-type: none"><li>• Coordinator: Dr Isabelle Czernichowski-Lauriol (BRGM): <a href="mailto:i.czernichowski@brgm.fr">i.czernichowski@brgm.fr</a></li><li>• Chair: Dr Nick Riley (BGS): <a href="mailto:nriley@bgs.ac.uk">nriley@bgs.ac.uk</a></li><li>• Management Board:<ul style="list-style-type: none"><li>○ Dr Isabelle Czernichowski-Lauriol (BRGM): <a href="mailto:i.czernichowski@brgm.fr">i.czernichowski@brgm.fr</a></li><li>○ Dr Anne Korre (Imperial College): <a href="mailto:a.korre@imperial.ac.uk">a.korre@imperial.ac.uk</a></li><li>○ Dr Roberto Martinez (S-IGME): <a href="mailto:ro.martinez@igme.es">ro.martinez@igme.es</a></li><li>○ Dr Vit Hladik (CzGS): <a href="mailto:vit.hladik@geology.cz">vit.hladik@geology.cz</a></li></ul></li><li>• Secretariat: Zeljka Kurelec (University of Zagreb – RGNF): <a href="mailto:info@cgseurope.net">info@cgseurope.net</a></li></ul>
<b>3. Project Objectives</b>
<ul style="list-style-type: none"><li>• Create a credible, independent and long-lasting pan-European scientific body of expertise to support widespread understanding of the technology and foster knowledge development and sharing.</li><li>• Provide an independent platform and reference source where national, European and international experts, institutes and regulators are able to access the most up-to-date results of CO<sub>2</sub> storage-related studies, share experiences and good practices, discuss the implementation of regulations, identify research needs to face upcoming challenges, and build new projects.</li><li>• Build a centralised information source of the status of CO<sub>2</sub> storage R&amp;D across the whole of Europe</li><li>• Reduce the gap in knowledge / awareness and in the implementation of geological storage of CO<sub>2</sub> between ‘forerunner’ countries and other countries where actions are not yet happening</li><li>• Contribute to the large scale demonstrations and industrial deployment of CCS by providing the necessary link between industrial developers and other vital players</li><li>• Support the implementation of the EU directive on the geological storage of CO<sub>2</sub> and other regulatory regimes through scientific advice, experience-sharing and dissemination of information</li></ul>
<b>4. Recent Milestones</b>
<ul style="list-style-type: none"><li>• April 13<sup>th</sup> – 14<sup>th</sup> Vilnius, Lithuania: <a href="#">1<sup>st</sup> CGS Europe Regional CCS awareness-raising workshop</a> ‘CO<sub>2</sub> capture and storage – response to climate change’, reaching out to stakeholders in the Baltic Sea region and central and eastern Europe</li><li>• 11<sup>th</sup> May 2011, San Servolo Island, Venice, Italy: 1<sup>st</sup> CGS Knowledge-sharing workshop: ‘Legal and regulatory issues – implementation of the EU directive on the geological storage of CO<sub>2</sub>’</li><li>• September 22<sup>nd</sup> – 23<sup>rd</sup> 2011, Brussels, Belgium: Internal communication workshop for press officers and researchers to share experiences in and knowledge of communication on CO<sub>2</sub> storage research</li></ul>

- October 17<sup>th</sup> – 19<sup>th</sup> 2011, Maria Laach, Germany: [2<sup>nd</sup> CGS Europe Knowledge-sharing workshop](#): ‘Natural analogues’
- November 24<sup>th</sup> 2011, Brussels, Belgium: SciTechEUROPE: [Masterclass and booth](#) on CO<sub>2</sub> Geological storage aimed at promoting exchange with industry stakeholders, funding agencies, academics and policy makers
- April 19<sup>th</sup> 2012, Venice, Italy: [3<sup>rd</sup> CGS Europe Knowledge Sharing workshop](#): ‘National research programmes’
- March 12<sup>th</sup> – 18<sup>th</sup> 2012, Leszcze, Poland. [CGS Europe Spring School](#) on CO<sub>2</sub> Geological Storage.
- June 13<sup>th</sup> – 14<sup>th</sup> 2012, Ankara, Turkey: [2<sup>nd</sup> CGS Europe CCS Awareness-raising workshop](#) ‘CO<sub>2</sub> Capture and Storage – regional awareness raising workshop’
- Article published: ‘[CO<sub>2</sub> Geological Storage](#)’. Public Service Review 22, p 200 – 201.
- [CO<sub>2</sub>GeoNet Brochure](#) translated and published in Bulgarian, Croatian, Czech, Estonian, Finnish, Latvian, Lithuanian, Russian, Serbian, Slovakian, Slovenian, Swedish and Turkish.
- [Knowledge Repository](#) on CGS website now includes summaries of EU and National projects, a searchable scientific publication list and links to CO<sub>2</sub> storage glossaries

## 5. Status

- Project established November 2010; 3 year duration funded as a coordination action by the EU Framework 7 programme
- 34 institutes involved from 24 EU Member States and 4 Associated Countries thereby representing most of Europe
- The focus is on coordination and integration mechanisms between the [CO<sub>2</sub>GeoNet Association](#) - the European Network of Excellence on the Geological Storage of CO<sub>2</sub> - and 23 other participants
- [CGS Europe website](#) at: <http://www.cgseurope.net> where more detailed project description and details of news and events can be found

**CO<sub>2</sub> Capture Project – Phase Three**  
 CSLF Project Status Report  
 August 2012

<b>1. Project Location</b>
Houston, USA (location of Brian Williams, Chairman of the CCP)
<b>2. Project Lead</b>
Mark Crombie, CCP Program Manager Mobile: +44 77 6988 6024 Tel: +44 1932 756 725 E-Mail: <a href="mailto:mark.crombie@uk.bp.com">mark.crombie@uk.bp.com</a>
<b>3. Project Objectives</b>
<p>The CO<sub>2</sub> Capture Project (CCP) is a partnership of several major energy companies working together to advance the technologies and to improve operational approaches in order to reduce costs and accelerate the deployment of CO<sub>2</sub> Capture and Storage (CCS).</p> <p>The CCP is currently in its third phase of activity – CCP3 (2009-2013). During the course of CCP3 the program will culminate in at least two field demonstrations of capture technologies and a series of monitoring field trials which will provide a clearer understanding of how to better monitor CO<sub>2</sub> in the subsurface.</p>
<b>4. Recent Milestones</b>
<p>Storage, Monitoring &amp; Verification Team</p> <ul style="list-style-type: none"> <li>• First phase of CO<sub>2</sub> Impurities Study completed, showing impact of stream impurities on underground CO<sub>2</sub> plume behaviour</li> <li>• Modular Borehole Monitoring (MBM) assembly deployed at Citronelle Field prior to injection</li> <li>• Injection started at Decatur, USA, with CCP3 SMV funded InSAR satellite technology deployed to detect surface deformation. Initial results are expected by the end of 2012</li> <li>• CO<sub>2</sub> Contingencies program (detection and intervention of unexpected migration) underway with cross-industry and academic input</li> </ul> <p>Capture Team</p> <ul style="list-style-type: none"> <li>• Oxy-combustion capture trial on a pilot-scale fluid catalytic cracking unit (one of the highest CO<sub>2</sub> emitting units of a refinery) completed, results available by the end of 2012</li> <li>• Oxy-fired once-through steam generator project Phase 2 (demonstration) preparation work continues. The demonstration run is scheduled in the spring of 2013</li> <li>• Oxy-firing tests in a simulated process heater completed. Evaluated feasibility of using commercial burners with modifications, for oxy-firing. Results available by end of 2012</li> <li>• Screening studies completed for novel natural gas combined cycle (NGCC) capture technologies, paving the way for potential future development and scale-up</li> <li>• New baselines established for refinery and heavy oil extraction using pre-combustion and oxy-firing technologies</li> </ul> <p>Policy &amp; Incentives Team</p> <ul style="list-style-type: none"> <li>• Investigation of various stakeholder issues at project and global level conducted, with the P&amp;I Team presenting the findings at the COP17 conference in Durban, South Africa</li> <li>• Review of regulatory issues for CCS projects study launched, results available by the end of 2012</li> </ul>

#### Communications

- Continued to provide resources to be used by NGOs, industry, media and policy makers – second CCP Annual Report published
- Launched digital version of In Depth brochure, June 2012

#### **5. Status**

The CCP is currently in its third phase of activity – CCP3, due to run between 2009 and 2013. See [www.co2captureproject.com](http://www.co2captureproject.com) for more information – including reports, factsheets and technical documents.

**CO2CRC Otway Project**  
 CSLF Project Status Report  
 April 2012

<b>1. Project Location</b>
Southwestern Victoria, Australia
<b>2. Project Lead</b>
<p>Matthias Raab – Program Manager, Storage</p> <ul style="list-style-type: none"> <li>• Phone: +61 3 8344 4309</li> <li>• Mobile: +61 417 066 318</li> <li>• Email: mraab@co2crc.com.au</li> <li>• CO2CRC, 3<sup>rd</sup> Flr, School of Earth Science, University of Melbourne, VIC 3010</li> </ul> <p>Rajindar Singh – Otway site Operations Manager</p> <ul style="list-style-type: none"> <li>• Mobile: +61 418 428 020</li> <li>• rssingh@co2crc.com.au</li> <li>• CO2CRC, 3<sup>rd</sup> Flr, School of Earth Science, University of Melbourne, VIC 3010</li> </ul>
<b>3. Project Objectives</b>
<p>The Otway project has been designed to demonstrate geological storage and monitoring of CO<sub>2</sub> under Australian conditions. It aims to provide technical information on geosequestration processes, technologies and monitoring and verification regimes that will help to inform public policy and industry decision-makers and assurance to the community.</p> <p>Stage 1: Continue Monitoring and Verification.</p> <p>Stage 2: Determine residual gas saturation (<math>S_{gr}</math>) of CO<sub>2</sub> from a single well test (Stage 2b) and determine smallest plume size of CO<sub>2</sub> that can be imaged by 4D time lapse seismic by injecting of up to a maximum of 30,000 tons (Stage 2c) into the Paaratte saline water formation.</p>
<b>4. Recent Milestones</b>
<ul style="list-style-type: none"> <li>• Stage 2b Injection/Withdrawal (Residual gas saturation) test completed in September 2011.</li> <li>• Community Reference Group (CRG) meeting held in May 2012.</li> </ul>
<b>5. Status</b>
<ul style="list-style-type: none"> <li>• Release of Stage 2b report for CO2CRC members planned for Oct 2012.</li> <li>• U-tube sampling of reservoir data, atmospheric monitoring, ground water sampling and soil testing continues as part of Stage 1 activities.</li> <li>• Stage 2c modeling peer review scheduled for Sep 2012. Review of static, dynamic, fault and seismic models for go/no-go decision.</li> <li>• Community to be continuously updated on forward plans through CRG meetings.</li> </ul>

**CO<sub>2</sub> Field Lab Project**  
CSLF Project Status Report  
September 2012

### 1. Project Location

The Project is coordinated by SINTEF Petroleum Research in Trondheim (Norway). The Field Laboratory is located at the Svelvik Ridge, 50 km south-west of Oslo (Norway).

Aerial photo showing the Svelvik Ridge. The CO<sub>2</sub> Field Laboratory is indicated by the yellow rectangle (150 m × 300 m)



### 2. Project Lead

- Project Manager: Maria Barrio; SINTEF ([maria.barrio@sintef.no](mailto:maria.barrio@sintef.no))
- Project Coordinator: Audun Bakk; SINTEF ([audun.bakk@sintef.no](mailto:audun.bakk@sintef.no))
- Site & HSE Coordinator: Marion Børresen, NGI ([marion.borresen@ngi.no](mailto:marion.borresen@ngi.no))
- Project Advisor: Erik Lindeberg, SINTEF ([erik.lindeberg@sintef.no](mailto:erik.lindeberg@sintef.no))

### 3. Project Objectives

- Determine the sensitivity of monitoring systems to detect shallow CO<sub>2</sub> subsurface movements & surface seepage
- Combination of appropriate monitoring technologies
- Definition of a monitoring protocol as a tool for certification
- Test and calibrate geo-models in well controlled conditions
- Inform the public about the safety of CO<sub>2</sub> storage by showing the performance of monitoring systems

### 4. Recent Milestones

- September 2011: Shallow CO<sub>2</sub> injection where 1600 kg CO<sub>2</sub> was injected at 18 meters depth in a permeable sandy formation (no cap rock)
- January 2012: Completed second draft of monitoring protocol
- February 2012: Technical workshop summarizing shallow injection experiment, Gardermoen, 8.2.2012
- August 2012: Operator chosen for drilling and completion of a 115 m deep injection well

### 5. Status

Project entered primo 2011 into its main (injection) phase (Phase 2). The shallow CO<sub>2</sub> injection (simulating leakage) during September 2011 was successful in order testing out several CO<sub>2</sub> monitoring techniques covering both the sub-surface and at the surface in the phreatic aquifer.

A 115 m deep well will be drilled and completed during September. The injectivity is planned to be assessed in this well right after drilling/completion.

Injection data and characterization data will now be further analyzed and backed up with simulations in order to update the geo-model. This should form a proper basis for further progress against the planned deeper injection in 2013/2014.

**CO<sub>2</sub> Technology Centre Mongstad Project**  
CSLF Project Status Report  
April 2012

<b>1. Project Location</b>
Mongstad, Norway
<b>2. Project Lead</b>
Tore Amundsen; Managing Director. <a href="mailto:toaam@tcmda.com">toaam@tcmda.com</a>
<b>3. Project Objectives</b>
<ul style="list-style-type: none"><li>• Develop technologies for CO<sub>2</sub>-capture capable of wide national and international deployment</li><li>• Reduce cost and technical, environmental and financial risks related to large scale CO<sub>2</sub>-capture</li><li>• Test, verify and demonstrate CO<sub>2</sub>-capture technology owned and marketed by Vendors</li><li>• Encourage the development of a market for such technology</li></ul>
<b>4. Recent Milestones</b>
<ul style="list-style-type: none"><li>• Amine plant mechanically complete, start-up in March 2012</li><li>• Chilled Ammonia Plant: mechanical installations on-going, start-up in Summer 2012</li><li>• Overall progress February 2012 approximately 90%</li></ul>
<b>5. Status</b>
<ul style="list-style-type: none"><li>• Investment of approximately USD 1 billion</li><li>• Construction progress: 90 %</li><li>• Operating organization established and preparing for operations</li></ul>

**Demonstration of an Oxyfuel Combustion System**  
 CSLF Project Status Report  
 April 2012

<b>1. Project Location</b>
Renfrew, Scotland, U.K.
<b>2. Project Lead</b>
Sang Hyeun Kim
<b>3. Project Objectives</b>
<ul style="list-style-type: none"> <li>• to demonstrate the successful performance of a full-scale (40MWt) OxyCoal™ burner firing at conditions pertinent to the application of an oxyfuel combustion process in a utility power generating plant;</li> <li>• to demonstrate the performance of an oxyfuel burner with respect to combustion efficiency, NO<sub>x</sub>, flame shape, and heat transfer characteristics;</li> <li>• to demonstrate the operational envelope of an oxyfuel burner with respect to flame stability, turndown, start-up, shutdown, and the transition between air- and oxyfuel-firing,</li> <li>• to demonstrate the safe operation of an oxyfuel combustion process under realistic operating conditions;</li> <li>• to generate sufficient performance data from the oxyfuel combustion process to inform future investment decisions; and</li> <li>• to demonstrate the level of technology readiness of the oxyfuel combustion process.</li> </ul>
<b>4. Milestones Achieved</b>
<ul style="list-style-type: none"> <li>• A full scale 40MWt OxyCoal™ burner was successfully demonstrated on air and oxyfuel operation. Safe and stable operation was achieved across a wide operational envelope. Oxyfuel flame stability was comparable to air firing experience.</li> <li>• Safe and smooth transitions between air and oxyfuel operation were demonstrated; three different transition methodologies were proven.</li> <li>• Turndown from full load to 40% load was demonstrated. Stable and well rooted flames were observed across the whole load range. Flame length reduces with load (as for air firing).</li> <li>• Realistic CO<sub>2</sub> levels were achieved (in excess of 75% v/v dry, and up to 85% v/v dry).</li> <li>• Project won Rushlight Energy Environmental Award</li> </ul>
<b>5. Status</b>
<ul style="list-style-type: none"> <li>• <b>Project successfully concluded</b></li> <li>• Final version of public report was issued February 2011 (available at DECC Publications Library website: <a href="http://www.decc.gov.uk/publications/">http://www.decc.gov.uk/publications/</a>)</li> <li>• Option for additional 2 year not exercised. Project partners pursuing individual development activities.</li> </ul>

**Fort Nelson Carbon Capture and Storage Project**  
Carbon Sequestration Leadership Forum Project Status Report  
August 2012

<b>1. Project Location</b>
Fort Nelson, British Columbia, Canada
<b>2. Project Lead</b>
<ul style="list-style-type: none"> <li>• Al Laundry (<a href="mailto:alaundry@spectraenergy.com">alaundry@spectraenergy.com</a>)</li> <li>• Ed Steadman (<a href="mailto:esteadman@undeerc.org">esteadman@undeerc.org</a>)</li> <li>• Jim Sorensen (<a href="mailto:jsorensen@undeerc.org">jsorensen@undeerc.org</a>)</li> <li>• Charles Gorecki (<a href="mailto:cgorecki@undeerc.org">cgorecki@undeerc.org</a>)</li> </ul>
<b>3. Project Objectives</b>
<p>The primary objective of the Fort Nelson Carbon Capture And Storage Feasibility Project is to verify and validate the concept of utilizing one of North America's large number of saline formations for large-scale CO<sub>2</sub> injection, proposed to be up to 2.2 Mt a year, of anthropogenic CO<sub>2</sub> for permanent storage. Specific goals include the following:</p> <ul style="list-style-type: none"> <li>• Cost-effective risk management, simulation, and monitoring, verification, and accounting (MVA) strategies for large-scale CO<sub>2</sub> storage in deep saline formations.</li> <li>• Testing and refinement of reservoir modeling intended to predict and estimate CO<sub>2</sub> injectivity (the potential for placing CO<sub>2</sub> into the reservoir). To confirm the practical CO<sub>2</sub> storage capacity for this site, areal extent and mobility of the supercritical CO<sub>2</sub> plume in the reservoir. To demonstrate improved methodologies to ensure that site characterization and MVA results better support risk management objectives and modeling efforts.</li> <li>• Testing strategies to predict the effects of CO<sub>2</sub> plume on the integrity of vertical and horizontal sealing formations, including the testing and modeling of key geomechanical and geochemical parameters. Includes assessing impact of injecting a cooler sour CO<sub>2</sub> stream into a hotter in situ saline fluid.</li> <li>• Test and model the reactions and fate of entrained H<sub>2</sub>S in the injected supercritical CO<sub>2</sub> stream and impacts on reservoir and containment rocks.</li> </ul>
<b>4. Recent Milestones</b>
<ul style="list-style-type: none"> <li>• Risk assessments have been updated using an expert panel approach. The update is based on newly acquired data sets that facilitate a better interpretation of the extent and geometry of the injection target.</li> <li>• Laboratory evaluation of reservoir properties has been conducted on core samples obtained from the C61E test well. Relevant properties including mechanical strength, porosity, permeability, and capillary entry pressures have been obtained.</li> <li>• Well work over and reservoir pressure testing at the existing exploratory well (C61E) were completed in the first quarter of 2012.</li> <li>• Geologic modeling and simulation have continued in this reporting period. A dynamic model based on the updated geologic model was constructed for the purpose of matching historical gas and water production, water disposal data, and scattered bottomhole pressures in areas near gas pools. Through the history-matching process, the geologic model was validated and improved.</li> </ul>

## 5. Status

- Project areas related to geological interpretation, laboratory evaluations, risk assessment, and planning of MVA activities are all ongoing and progressing.
- Locations, geometries, and materials for the project's second exploratory well and for an extensive 3-D seismic program are planned for completion in 2012–2013.

**Geologic CO<sub>2</sub> Storage Assurance at In Salah, Algeria**  
 CSLF Project Status Report  
 August 2012

<b>1. Project Location</b>
In Salah, Algeria, Africa
<b>2. Project Lead</b>
Allan Mathieson: <a href="mailto:allan.mathieson@uk.bp.com">allan.mathieson@uk.bp.com</a> BP Alternative Energy, Chertsey Road, Sunbury, Middlesex TW16 7LN, UK
<b>3. Project Objectives</b>
<ul style="list-style-type: none"> <li>• Provide assurance that secure geological storage of CO<sub>2</sub> can be cost-effectively verified and that long-term assurance can be provided by short-term monitoring.</li> <li>• Demonstrate to stakeholders that industrial-scale geological storage of CO<sub>2</sub> is a viable GHG mitigation option.</li> <li>• Set precedents for the regulation and verification of the geological storage of CO<sub>2</sub>, allowing eligibility for GHG credits</li> </ul>
<b>4. Recent Milestones</b>
<ul style="list-style-type: none"> <li>• Transfer of regular monitoring activities to the JV Operations team completed</li> <li>• Completed monitoring and detailed modeling of shallow potable aquifer</li> <li>• Completed assessments of microseismic data suggesting events during injection came from the injection horizon depth</li> <li>• Installing pressure transducers in shallow (potable) aquifer wells to monitor for irregularities in pressure</li> <li>• Results of Quantitative Risk Assessment incorporated into field operations and monitoring plans</li> <li>• A project website is available at: <a href="http://www.insalahco2.org">www.insalahco2.org</a></li> </ul>
<b>5. Status</b>
<ul style="list-style-type: none"> <li>• Stored 3.89mmt CO<sub>2</sub> in a deep saline aquifer (1900m deep, 20-22m thick, 13% porosity, 10mD permeability). Currently reviewing injection strategies and operational procedures to reflect recent monitoring information.</li> </ul>

**Gorgon CO<sub>2</sub> Injection Project**  
 CSLF Project Status Report  
 September 2012

<b>1. Project Location</b>	
Barrow Island, Western Australia, Australia	
<b>2. Project Lead</b>	
Inquiries in relation to the project should be addressed to: Chevron Australia Pty Ltd John Torkington - Senior Advisor, Climate Change Policy trkn@chevron.com	
<b>3. Project Objectives</b>	
The project aims to demonstrate the safe commercial scale application of greenhouse gas storage technologies at a scale not previously attempted. <ul style="list-style-type: none"> <li>• It is proposed to inject over 100 million tonnes of carbon dioxide at rates of between 3.5 and 4 million tonnes per annum.</li> <li>• The Gorgon Joint Venture Participants have given a public commitment to the disclosure of monitoring data associated with the project in order to help inform the community and other project proponents about the progress of the project.</li> <li>• The Gorgon Joint Venture Participants propose the sharing of lessons learned in areas such as site selection, environmental impact assessment, policy and regulatory development.</li> </ul>	
<b>4. Recent Milestones</b>	
1998	Commence detailed site selection studies
2003	Identified the Dupuy Formation as the most suitable injection site
2003	Commenced environmental impact assessment process
2003	Barrow Island Act 2003 (WA) proclaimed. This act includes the world's first greenhouse gas storage legislation
2005	Published the Gorgon Project Environmental Impact Statement / Environmental Review and Management Programme (EIS/ERMP)
2007	Received Western Australian and Australian Government environment approval the Gorgon Project.
2008	Published the Public Environmental Review (PER) for a revised and expanded Gorgon Project
2009	Received Western Australian and Australian Government environment approval of the revised and expanded Gorgon Project.
2009	Project receives final approvals, sanction from Joint Venture participants and moves into construction (September 2009) Order placed for carbon dioxide compressors (October 2009). Official groundbreaking on Barrow Island (December 2009)
2011	Petroleum Pipeline Licence granted (December 2011) CO <sub>2</sub> injection pipeline construction contract awarded (December 2011)
The project has progressed through its early development stages including site selection, site appraisal, facilities front end engineering and design and has obtained high level approvals including environmental approvals and approval to dispose of carbon dioxide by underground injection. The project is fully funded and construction has commenced.	

## 5. Status

The Gorgon Carbon Dioxide Injection Project is an integral component of the much larger \$43 billion Gorgon Project which involves the development of the several deepwater gas fields and the development of a gas processing facility on Barrow Island. The Australian Government has committed \$60 million to the Gorgon Carbon Dioxide Injection Project as part of the Low Emissions Technology Demonstration Fund (LETDF).

The Gorgon Project is operated by an Australian subsidiary of Chevron and is a joint venture of the Australian subsidiaries of Chevron (approximately 47 percent), ExxonMobil (25 percent) and Shell (25 percent), Osaka Gas (1.25 percent), Tokyo Gas (one percent) and Chubu Electric Power (0.417 percent).

The Gorgon Project aims to export approximately 15 million tonnes of liquefied natural gas annually to east Asia markets and up to 300TJ of domestic gas into Western Australian markets.

In early 2011 the Gorgon Joint Venture Participants announced plans to add a further 5 million tonnes per annum processing train. The proposal is now subject to environmental review.

Achievements as of July 2012 include:

- The Gorgon Project remains on schedule for first gas in 2014. June 2012 marked 30 months of construction on Barrow Island and work continues to focus on constructing accommodation, site preparation and logistics activities.
- Dredging on the project has progressed well and is nearing completion.
- A Horizontal Direction Drilling program, which will bring the feed gas pipelines onto Barrow beneath an undisturbed shoreline, commenced in April 2011.
- More than \$17 billion has already been committed to Australia industry with more than 9,000 jobs created. Over the construction period about \$20 billion will flow to Australian industry.
- From the commencement of the Gorgon Project in September 2009, quarantine screening has been completed on more than 180,000 passengers and over 660,000 tonnes of freight. In addition, more than 26,000 personnel have received quarantine training specific to their role. One hundred and thirty audits have been completed to ensure contractors are meeting quarantine obligations and more than 200 quarantine compliant vessels successfully mobilised. The on-island workforce is steadily increasing with approximately 4,000 people. At peak construction around 5,000 will be housed on Barrow Island.
- The Gorgon Project's Quarantine Management System has won numerous awards including:
  - 2011 APPEA Environment Award
  - 2011 WA Engineering Excellence Award - Environment Category
  - 2011 WA Engineering Excellence Award- High Commended in Management of Engineering
- The first of the Project's major modules being built in Korea in has arrived on Barrow Island. In total there will be 48 modules weighing around 200,000 tonnes. In addition on the pre-assembled racks (PARs) and units (PAUs) being constructed in China and Indonesia have started arriving on the island.

- In October 2010, the Project received world recognition for its Gorgon Carbon Dioxide Injection Project from the Carbon Sequestration Leadership Forum at its annual meeting in Warsaw, Poland.
- For more details on the latest Project news visit <http://www.chevronaustralia.com>

## 6. Project Photographs (for the Gorgon Project in general)

The onshore construction site.





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The Marine Offloading Facility (MOF) extending from the gas plant footprint. The MOF will enable the offloading of materials required for the Gorgon Project.



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The accommodation village is nearing completion.



**IEAGHG Weyburn-Midale CO<sub>2</sub> Monitoring and Storage Project**  
 CSLF Project Status Report  
 April 2012

<b>1. Project Location</b>
Weyburn and Midale Units, Weyburn area, southeast Saskatchewan, Canada
<b>2. Project Lead</b>
<ul style="list-style-type: none"> <li>▪ Floyd Wist (Saskatchewan Energy and Resources), Chair, Leading Sponsors Executive Committee (LSEC)</li> <li>▪ Neil Wildgust (Petroleum Technology Research Centre), Chief Project Officer, Technical / Research Component</li> <li>▪ Frank Mourits (Natural Resources Canada), Project Integrator / Coordinator Policy Component</li> </ul>
<b>3. Project Objectives</b>
<ul style="list-style-type: none"> <li>▪ Develop a comprehensive Best Practices Manual for CO<sub>2</sub> geological storage, which will guide all aspects of future CO<sub>2</sub>-EOR storage projects.</li> <li>▪ Building on the successes of the First Phase, focus the technical research component on site characterization, wellbore integrity, monitoring and verification, and performance (risk) assessment.</li> <li>▪ Focus the policy component on public communications and outreach, regulatory issues and the business environment.</li> <li>▪ Ensure integration across technical research and policy components.</li> </ul>
<b>4. Recent Milestones</b>
<ul style="list-style-type: none"> <li>▪ March 2009 – Public Communications and Outreach work program and budget approved by LSEC. Work on CCS website and outreach activities commenced.</li> <li>▪ June 2009 – Project Integration and Sponsors Meeting (PRISM-4), Regina, Saskatchewan.</li> <li>▪ June 2009 – an expert workshop was held in Calgary as part of the ongoing Risk Assessment work.</li> <li>▪ October 2009 – a workshop was held in Ottawa with researchers involved in modelling tasks.</li> <li>▪ January 2010 – Project Integration and Sponsors’ Meeting (PRISM-5), Ottawa, Ontario.</li> <li>▪ March 2010 – Completion of a study that clarifies the regulatory framework governing injection and storage of CO<sub>2</sub> in Saskatchewan (second major deliverable under the Regulatory Theme).</li> <li>▪ January / May 2010 – Additional funding of \$2.2 million by NRCan and \$3 million by DOE/NETL announced for expanded well integrity program and other research. Work funded by NRCan must be completed by March 2011 and that by DOE by December 2012.</li> <li>▪ The new <a href="http://www.ccs101.ca">www.ccs101.ca</a> website was launched at the 9<sup>th</sup> Carbon Capture and Sequestration Conference in Pittsburgh (May 10-13, 2010).</li> <li>▪ June 2010 - Project Integration and Sponsors’ Meeting (PRISM-6), Saskatoon, Saskatchewan.</li> <li>▪ December 2010 – Project Integration and Sponsors’ Meeting (PRISM-7), Calgary, Alberta.</li> </ul>

- March 31, 2011 – Most research completed.
- February 2012 – Project Integration and Sponsors’ Meeting (PRISM-8), Denver, Colorado.

## 5. Status

- The static geological model has been completed will store much of the data generated within the project.
- A model using the percolation-invasion methodology for determining the long-term fate of CO<sub>2</sub> has been constructed and in the final stages of development.
- The in-field wellbore integrity testing program was completed in March 2011. This entailed performing drilling slots into the cement sheath and performing pressure-transient tests (PTT) to determine communication within the cement. Samples of cement were also collected. The PTT results and cement samples are currently being analyzed.
- A shallow groundwater survey was completed fall 2009. This survey complements similar surveys performed since the inception of the project in 2000.
- Three reservoir fluid sampling monitoring surveys were completed in October 2008, May 2009 and October 2009. Additional surveys were conducted in May and October of 2010 for a total of 16 monitoring surveys for reservoir fluids. No additional surveys are planned within the PTRC program.
- Passive micro-seismic monitoring is ongoing. Surveys to date have indicated very minimal response to CO<sub>2</sub> injection.
- Extensive work is being performed to improve the rock physics model used to assist in calibrating the time-lapse 3D seismic for CO<sub>2</sub> saturations.
- Stochastic modelling has been completed to integrate both geophysical and geochemical databases to understand CO<sub>2</sub> behavior within the reservoir.
- Major work items under the Regulatory Theme have been completed. The Theme Lead will maintain a watching brief to keep the completed studies up-to-date. Presentations on these studies to government agencies, conferences and other events are being made on request.
- Under the Public Communications and Outreach Theme, the now well-established [www.ccs101.ca](http://www.ccs101.ca) website is continually being improved and updated. A display stand with CCS information materials was developed for use at conferences and conventions (e.g. science teachers) as well as Open Houses for large CCS demonstration projects in Canada. Focus group testing activities are being developed for the remainder of 2011.
- Most research was completed by March 31, 2011. Results have been submitted and are in technical review. Several tasks, including some new work, will extend beyond this date and be completed by the end of 2011.
- A soil gas monitoring survey scheduled for spring 2011 was postponed due to extreme flooding in SE Saskatchewan until October 2011. Long-term flux measurements were conducted to determine biogenic activity within the soils.
- Project leads participated in the investigation by Cenovus into allegations of CO<sub>2</sub> leaks on the Kerr farm near the Weyburn field. A report, issued in November 2011, found no evidence of any leakage.
- The project’s key deliverable, the Best Practices Manual, is scheduled to be completed by September 30, 2012.
- A special panel session of presentations on the Best Practices Manual will be held at the 11<sup>th</sup> Annual Carbon Capture, Utilization and Sequestration Conference in Pittsburgh (April 30 – May 3, 2012).

- A similar session is being planned for the GHGT-11 conference in Kyoto in November 2012.
- A special supplement to the International Journal of Greenhouse Gas Control, comprising a collection of papers on the results of the research undertaken in the project, is being prepared for publication in late 2012.

**Lacq CO<sub>2</sub> Capture and Storage Project**  
 CSLF Project Status Report  
 August 2012

<b>1. Project Location</b>
France – South West
<b>2. Project Lead</b>
<ul style="list-style-type: none"> <li>• Jacques Monne : R&amp;D Manager, <a href="mailto:jacques.monne@total.com">jacques.monne@total.com</a></li> <li>• Pierre Valette : Production Manager, <a href="mailto:pierre.valette@total.com">pierre.valette@total.com</a></li> </ul>
<b>3. Project Objectives</b>
<ul style="list-style-type: none"> <li>• The overall aim of this project is to test the industrial-scale feasibility of an integrated CCS chain within industrials facilities.</li> <li>• To demonstrate the feasibility of converting an existing 30 MWth industrial boiler to oxycombustion in order to confirm the following targets of           <ul style="list-style-type: none"> <li>○ reduction of capture cost compared to classical post capture technologies</li> <li>○ reduction of overall direct and indirect CO<sub>2</sub> emissions if indirect emissions are not captured</li> </ul> </li> <li>• To develop and apply geological storage qualification methodologies, monitoring and verification techniques on a real operational case to prepare future larger scale long term storage projects</li> </ul>
<b>4. Recent Milestones</b>
<ul style="list-style-type: none"> <li>• The design of an optimized up-scaled oxy boiler from 30 MWth to 200 MWth is on - going. A CFD model has been built based on the results of the test campaign performed in November 2011 concerning the heat fluxes and exit gas temperature measurements.</li> <li>• 45000 tonnes of CO<sub>2</sub> have been injected (End of August) from the beginning of this experimentation.</li> <li>• The R&amp;D down hole micro seismic arrays system is working well. The data interpretation is still on-going.</li> <li>• The disponibility factor during April has been 1 for the oxyboiler.(Best month)</li> <li>• The pilot has been stopped (from 3<sup>rd</sup> June up to 19<sup>th</sup> July) for performing preventive maintenance and for doing an in-depth analysis of the recorded micro seismic events without CO<sub>2</sub> injection.</li> </ul>
<b>5. Status</b>
<ul style="list-style-type: none"> <li>• Reservoir pressure evolution is as predicted.</li> <li>• No significant seismic event recorded.</li> <li>• Results of environmental monitoring: no variation recorded compare to the base line.</li> </ul>

**Quest CCS Project**  
CSLF Project Status Report  
April 2012

<b>1. Project Location</b>
The Quest CCS Project is being proposed at Shell's Scotford Upgrader located near Edmonton, Alberta, Canada.
<b>2. Project Lead</b>
<ul style="list-style-type: none"><li>• Len Heckel, Quest Business Opportunity Manager, Shell Canada <a href="mailto:Len.Heckel@shell.com">Len.Heckel@shell.com</a></li><li>• Project Contact Paul Hagel, Senior Government Relations Advisor <a href="mailto:paul.hagel@shell.com">paul.hagel@shell.com</a></li></ul>
<b>3. Project Objectives</b>
<ul style="list-style-type: none"><li>• The Quest CCS project is being advanced on behalf of the AOSP, a joint venture among Shell Canada (60 per cent) Chevron Canada Limited (20 per cent) and Marathon Oil Canada Corporation (20 per cent).</li><li>• Quest is a fully integrated capture, transportation, storage and monitoring project, which will capture and store up to 1.2 million tonnes/yr of CO<sub>2</sub> from the Shell Scotford Oil Sands Upgrader in central Alberta, Canada. The CO<sub>2</sub> will be transported via pipeline approximately 80 km northeast of Scotford and stored underground (2000 m to 2300m) in a deep geological formation (Basal Cambrian Sands).</li><li>• Demonstration by 2015 of technology, innovation and cost for the design, construction and operation of CO<sub>2</sub> capture from steam methane reforming associated with an existing oil sands upgrader</li><li>• Demonstration by 2015 of technology, innovation and cost associated with the compression, and pipeline transportation up to 80km from the capture facilities to the storage site</li><li>• Demonstration by 2015 of technology, innovation and cost associated with appraisal, design, construction, operation and monitoring (MMV) of CO<sub>2</sub> storage in a deep saline aquifer (Basal Cambrian Sands) in central Alberta</li><li>• Demonstration of a significant reduction in CO<sub>2</sub> footprint from an existing oil sands operation through an industrial, commercial-scale CCS application.</li><li>• Continuous operation beyond 2015 of the commercial scale CCS project associated with the Scotford oil sands upgrader for a minimum of 10 years.</li></ul>
<b>4. Recent Milestones</b>
<ul style="list-style-type: none"><li>• October 11<sup>th</sup> 2011: Shell Canada receives a certification from Det Norske Veritas (DNV) regarding the suitability of the project's Storage Development Plan for the project. The certification, which is the first of its kind, is the result of a panel review by independent experts who assessed the SDP. This panel concluded that the planned storage zone has sufficient injectivity and capacity for the project life, that the storage zone has sufficient containment attributes, that the risks have been comprehensively assessed with appropriate risk management plans, and that the MMV plan is fit-for-purpose to demonstrate containment and conformance to predicted storage properties</li></ul>

- March 6-9<sup>th</sup> 2012: The Province of Alberta's Energy Resources Conservation Board (ERCB) conducts a public regulatory hearing on the Quest Project. The hearing provided the opportunity for any objectors with standing to table concerns regarding the project. Additionally, the opportunity was given to the ERCB panel and their experts to question the Quest team on any aspect of the project prior to providing a recommendation as to whether provincial regulatory approval should be given to proceed. The Board hearing report is expected in the May to June 2012 timeframe.

## 5. Status

- Following an anticipated favourable provincial and federal regulatory review, the project joint venture owners will make a final investment decision in 2012, subject to internal confirmation of economic and technical feasibility and regulatory conditions. This important milestone represents the final decision to proceed with the project.
- With CO<sub>2</sub> injection planned for 2015, the Quest Project will join only a handful of CCS projects around the world that are injecting CO<sub>2</sub> at a commercial scale. Shell is working with governments and other experts globally on both political and technical levels to facilitate the development and wide-scale deployment of CCS and is involved in progressing a number of projects around the world, across a wide range of sectors.
- Shell will be working with the Province of Alberta and the Government of Canada to develop a broad knowledge sharing program in accordance with the signed funding agreements with these governments. This will further assist the development of wide-scale CCS deployment
- For more information, check out [www.shell.ca/quest](http://www.shell.ca/quest) or contact [paul.hagel@shell.com](mailto:paul.hagel@shell.com)

**Regional Carbon Sequestration Partnerships Project**  
 CSLF Project Status Report  
 April 2012

<b>1. Project Location</b>
Various locations in United States and Canada
<b>2. Project Lead</b>
National Regional Carbon Sequestration Partnership (RCSP) Initiative Managed by the U.S. Department of Energy National Energy Technology Laboratory (NETL) <ul style="list-style-type: none"> <li>• John Litynski, Technology Manager, Carbon Storage Program, NETL (<a href="mailto:john.litynski@netl.doe.gov">john.litynski@netl.doe.gov</a>)</li> <li>• Traci Rodosta, Director, Sequestration Division, NETL (<a href="mailto:traci.rodosta@netl.doe.gov">traci.rodosta@netl.doe.gov</a>)</li> <li>• Traci Rodosta, Regional Partnerships Coordinator (Acting), NETL (<a href="mailto:traci.rodosta@netl.doe.gov">traci.rodosta@netl.doe.gov</a>)</li> </ul>
<b>3. Project Objectives</b>
<ul style="list-style-type: none"> <li>• Coordinate this government/industry effort of seven RCSPs tasked with determining the most suitable technologies, regulations, and infrastructure needs for carbon capture, transport, and storage across areas of the United States and Canada.</li> <li>• Develop the infrastructure necessary for the future deployment and commercialization of carbon capture and storage (CCS) as a critical strategy mitigation of greenhouse gas emissions and climate change.</li> <li>• Implement the RCSP program in three phases:           <ul style="list-style-type: none"> <li>○ Characterization Phase (2003 – 2005): The partnerships completed the initial characterization of their regions’ potential to store CO<sub>2</sub> in different geologic formations.</li> <li>○ Validation Phase (2005 – 2012): The partnerships are validating the most promising regional storage opportunities through a series of small-scale field tests. This phase builds upon Characterization Phase accomplishments and begins field testing of geologic and terrestrial storage technologies to provide the technical foundation for Development Phase activities.</li> <li>○ Development Phase (2008 – 2018+): The partnerships will implement large-scale field testing involving at least one million tons of CO<sub>2</sub> per project to confirm that CO<sub>2</sub> injection and storage can be achieved safely, permanently, and economically. These tests will include one to three years of site characterization; one to three years of injection; and two or more years of post-injection monitoring, verification, accounting, and assessment (MVAA).</li> </ul> </li> </ul>
<b>4. Recent Milestones</b>
<ul style="list-style-type: none"> <li>• Validation Phase field activities were initiated in 2005 and are scheduled to be completed in 2012. A total of 1.35 million metric tons has been injected in 18 out of 19 small scale field tests. The final test in the Columbia Basin (Basalt pilot test) is scheduled to be completed in late 2012. Below are the results from the completed tests.</li> </ul> <p><b>Completed Saline Formation CO<sub>2</sub> injection field tests:</b></p> <p><u>Midwest Geological Sequestration Consortium (MGSC)</u></p> <ul style="list-style-type: none"> <li>○ Illinois Basin – injection site was merged with Phase III site, characterization well was drilled in Phase II.</li> </ul> <p><u>Midwest Regional Carbon Sequestration Partnership (MRCSP)</u></p> <ul style="list-style-type: none"> <li>○ Michigan Basin – two injection tests totaling 60,000 metric tons in the Bass Islands Dolomites completed in July 2009.</li> </ul>

- Cincinnati Arch – injection of approximately 900 metric tons in the Mt. Simon was completed in September 2009.
- Appalachian Basin – injection of less than 50 metric tons was completed in September 2008 targeting the Oriskany and Clinton Sandstones.

Southeast Regional Carbon Sequestration Partnership (SECARB)

- Mississippi Gulf Coast – injection of approximately 2,740 metric tons into the Lower Tuscaloosa Formation at Plant Daniel in late 2008.

West Coast Regional Carbon Sequestration Partnership (WESTCARB)

- Colorado Plateau – evaluation completed in Naco and Martin Sandstones in December 2009.

**Completed Enhanced Oil or Gas Recovery and CO<sub>2</sub> storage:**

Midwest Geological Sequestration Consortium (MGSC)

- Illinois Basin – Huff' n Puff test in the Weller Sandstone was completed in March 2007 in Fayette County, Illinois; approximately 39 metric tons of CO<sub>2</sub> were injected and 93 barrels of oil produced.
- Illinois Basin – Mumford Hills EOR field test in the Clore Formation was completed in early 2010 in Posey County, Indiana; approximately 6,295 metric tons of CO<sub>2</sub> was injected at the rate of 22 to 27 metric tons per day; incremental oil production increased over the pre-CO<sub>2</sub> injection oil rate and current EOR production is 1,590 stock tank barrels.
- Illinois Basin – Sugar Creek EOR field test was completed in 2010 in Hopkins County, Kentucky; approximately 6,595 metric tons of CO<sub>2</sub> was injected at a rate of 22 metric tons per day into the Jackson Sandstone; oil recovery rate did increase despite early CO<sub>2</sub> breakthrough at one well and current oil production is 2,110 stock tank barrels.

Plains CO<sub>2</sub> Reduction Partnership (PCOR)

- Williston Basin – Huff' n Puff in the Mississippian Canyon Formation was completed in June 2009 in Williams County, North Dakota; approximately 400 metric tons (440 short tons) were injected, producing through September 17th, 2009, approximately 242 barrels of oil and 1,991,000 cubic feet of natural gas.
- Zama Oil Field – Since December 2006, acid gas (70% CO<sub>2</sub> and 30% H<sub>2</sub>S) has been continuously injected at a depth of 4,900 feet into the Zama F Pool, one of over 800 pinnacle reefs in the Middle Devonian Keg River Formation in the Zama subbasin, Alberta, Canada. Through January 2011, over 60,000 metric tons of CO<sub>2</sub> has been injected, resulting in incremental oil production over 50,000 barrels.

Southeast Regional Carbon Sequestration Partnership (SECARB)

- Cranfield Oil Field – initial injection of 627,744 metric tons into the Tuscaloosa Formation was completed in July 2008 for enhanced oil recovery, project transitioned into Development Phase and to date more than one million tons of CO<sub>2</sub> has been injected.

Southwest Regional Partnership on Carbon Sequestration (SWP)

- Aneth Oil Field – as of December 2009, approximately 292,000 metric tons have been injected at the detailed study area into the Deep Creek and Ismay Formations within the Paradox Basin for EOR operations by January 1, 2010.
- SACROC – injection of approximately 78,000 metric tons were injected into the Horseshoe Atoll and Pennsylvania Reef/Bank Play in the Permian Basin at the detailed study area.

**Completed Enhanced Coalbed Methane (ECBM) CO<sub>2</sub> tests:**

Midwest Geological Sequestration Consortium (MGSC)

- Illinois Basin – the 91 metric tons injection was completed in July 2008 into the Pennsylvanian Carbondale Formation at 2-3 tons per day, methane gas was produced as a result.

#### Plains CO<sub>2</sub> Reduction Partnership (PCOR)

- Williston Basin – CO<sub>2</sub> injection was completed in March 2009 into a lignite coal seam in the Fort Union Formation in Burke County, North Dakota. Injection of 80 metric tons (90 short tons) of CO<sub>2</sub> took place over a period of 16 days.

#### Southwest Regional Partnership on Carbon Sequestration (SWP)

- San Juan Basin – approximately 16,700 metric tons were injected into the coals in the Upper Cretaceous Fruitland Formation, and low amounts of additional methane may have been subsequently produced.

#### Southeast Regional Carbon Sequestration Partnership (SECARB)

- Central Appalachian Basin – injection of 907 metric tons into coals in the Pocahontas and Lee Formations was completed in early 2009.
- Black Warrior Basin – injection of approximately 252 metric tons of CO<sub>2</sub> was injected into the Black Creek, Mary Lee and Pratt Coals at the Blue Creek Coal Degasification Field, Tuscaloosa County, Alabama.

**Terrestrial Sequestration Projects:** Eleven successful terrestrial sequestration projects have been completed during the Validation Phase, and additional projects have continued through 2012. Project categorization includes agriculture soils, soil reclamation, afforestation, accounting/aggregation and wetlands reclamation. NETL has developed a Best-Practices manual for Terrestrial Storage of Carbon Dioxide that covers land types and management methods that can maximize carbon storage in vegetation and soil. It also covers the analytical techniques necessary to monitor, verify, and account for terrestrially stored carbon, which is required for this carbon to be traded. Results and lessons learned from the Regional Carbon Sequestration Partnerships terrestrial field trials are discussed as example terrestrial carbon storage practices. This manual is available at:

[http://www.netl.doe.gov/technologies/carbon\\_seq/refshelf/BPM\\_Terrestrial.pdf](http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM_Terrestrial.pdf)

- Development Phase activities began in 2008 and will continue for approximately 10+ years. There are eight large-volume injection tests initiating between 2009 –2014. These injection tests are being conducted in saline and oil/natural gas bearing formations.

#### **Partnership Development Project Status:**

##### Big Sky Regional Carbon Sequestration Partnership (Big Sky)

- Kevin Dome Project. The Partnership is planning to inject one million metric tons over a four year period. The natural source of CO<sub>2</sub> will be extracted from the Kevin Dome and injected into the primary target, Duperow Formation, or a secondary target, Souris River Formation in Northern Montana. The Partnership has injection scheduled for mid 2013.

##### Midwest Geological Sequestration Consortium (MGSC)

- Decatur Project. The Partnership has initiated the large-scale saline formation injection in the Illinois Basin that will inject 365,000 metric tons of CO<sub>2</sub> per year into the Mt. Simon Sandstone for three years totaling one million metric tons. The source of the CO<sub>2</sub> will be the Archer Daniels Midland Company (ADM), ethanol production facility in Decatur, Illinois. The project has injected approximately 100,000 metric tons into the Mt. Simon Sandstone.

##### Midwest Regional Carbon Sequestration Partnership (MRCSP)

- Michigan Basin Project. The Partnership will conduct a large scale injection test in Otsego County, Michigan Basin, injecting one million metric tons of CO<sub>2</sub> over a four year period. The source of the CO<sub>2</sub> will be Core Energy via natural gas processing facility and the test is scheduled to begin in the 2012/2013 timeframe.

#### Plains CO<sub>2</sub> Reduction Partnership (PCOR)

- Bell Creek Project. The first of the Partnership's two development projects is located in the Powder River Basin in Montana. In partnership with Denbury Resources Inc, the Bell Creek Project will couple EOR and CO<sub>2</sub> storage by monitoring the injection of over one million metric tons of CO<sub>2</sub> into the Muddy Sandstone Formation. The source of CO<sub>2</sub> is the Lost Cabin/Madden Gas Plant operated by ConocoPhillips. Denbury Onshore LLC is currently constructing a 232-mile (373-kilometer) CO<sub>2</sub> pipeline (known as the Greencore pipeline) which will deliver CO<sub>2</sub> from the COP Lost Cabin gas-processing plant to the Bell Creek Oil Field. The pipeline is scheduled to be completed by December 2012. Injection is anticipated in early 2013.
- Fort Nelson Project. The second development phase project, the Fort Nelson project, will have the capability to capture more than two million metric tons of sour CO<sub>2</sub> (95% CO<sub>2</sub> and 5% H<sub>2</sub>S) from one of the largest gas-processing plants in North America and inject into the Devonian Elk Point Group/Sulphur Point Formation, Alberta Basin. The source of the CO<sub>2</sub> will be Spectra Energy's Fort Nelson Natural Gas Processing Plant, and injection is anticipated in 2014.

#### Southeast Regional Carbon Sequestration Partnership (SECARB)

- Cranfield Early Test Project. The first of the Partnership's two development projects began injection in April 2009 and has injected nearly three million metric tons of CO<sub>2</sub> into the Lower Tuscaloosa Formation. The source of CO<sub>2</sub> is the Jackson Dome, and it is being delivered via Denbury Resources' CO<sub>2</sub> pipeline.
- Citronelle Dome Anthropogenic Project. This second development project the Partnership is conducting is an integrated capture and injection project that will inject approximately 250,000 metric tons of CO<sub>2</sub> over two years into the Paluxy Formation. The source of the CO<sub>2</sub> is a 25 megawatt (MW) flue gas stream from Southern Company's Plant Barry Power Station located near Mobile, Alabama. CO<sub>2</sub> injection is anticipated to begin in May 2012.

#### Southwest Regional Partnership on Carbon Sequestration (SWP)

- Gordon Creek Project. The Partnership plans to perform a large scale injection into the primary target formation, Jurassic-aged Navajo Sandstone with potential injection into the secondary target, the Estrada Formations. The Partnership anticipates over one million metric tons of CO<sub>2</sub> to be injected into the Wasatch Plateau over a four year period utilizing a natural source of CO<sub>2</sub>. Injection is scheduled to commence in the 2013/2014 timeframe.

#### West Coast Regional Carbon Sequestration Partnership (WESTCARB)

- Development Phase. The Partnership plans to facilitate successful commercial-scale carbon capture and storage (CCS) development through expanded and enhanced regional characterization and R&D to identify and address CCS implementation issues. This includes: (1) working with state agencies and universities to further characterize geologic storage potential and capacity; (2) working with industry partners to define promising sites and facilitate the process for developing commercial-scale CCS projects; and (3) working with policymakers and regulatory agencies to identify impediments and solutions to future CCS project development.

#### **Additional Sequestration Program RCSP Updates:**

- The 2011 Project Portfolio is available and includes information on the Carbon Storage Program, Regional Partnerships, Carbon Storage Program R&D Focus Areas (Project Fact Sheets) and American Recovery and Reinvestment Act Sequestration projects. Please see the link below for more information:

[http://www.netl.doe.gov/technologies/carbon\\_seq/refshelf/project%20portfolio/2011/index.html](http://www.netl.doe.gov/technologies/carbon_seq/refshelf/project%20portfolio/2011/index.html)

- The third edition of the Carbon Sequestration Atlas of the United States and Canada is now available online:  
[http://www.netl.doe.gov/technologies/carbon\\_seq/refshelf/atlasIII/index.html](http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasIII/index.html)  
The 2010 Carbon Sequestration Atlas includes an overview of DOE's Storage Program, International Collaborations, National Risk Assessment, RCSP Activities, Refined CO<sub>2</sub> Storage and Prospective Storage Resources within the RCSPs, Worldwide CCS projects and regulatory issues and NATCARB's improved databases and GIS system. The fourth edition of the Carbon Storage Atlas of the United States and Canada will be available in November 2012.
- Six of the seven anticipated Best Practices Manuals and one case history document based on the lessons learned from the RCSP Initiative have been completed and are available online:  
[http://www.netl.doe.gov/technologies/carbon\\_seq/refshelf/refshelf.html](http://www.netl.doe.gov/technologies/carbon_seq/refshelf/refshelf.html)
  - Monitoring, Verification, and Accounting of CO<sub>2</sub> Stored in Deep Geologic Formations
  - Best Practices for Public Outreach and Education for Carbon Storage Projects
  - Site Screening, Site Selection, and Initial Characterization for Storage of CO<sub>2</sub> in Deep Geologic Formations
  - Geologic Storage Formation Classification: Understanding Its Importance and Impacts on CCS Opportunities in the United States
  - Risk Analysis and Simulation for Geologic Storage of CO<sub>2</sub>
  - Best Practices for Terrestrial Sequestration of Carbon Dioxide
  - Regional Carbon Sequestration Partnerships' Simulation and Risk Assessment Case History
- NETL is continuing ongoing collaboration with Interstate Oil and Gas Compact Commission (IOGCC), through SECARB, to evaluate potential for subsurface geological storage of CO<sub>2</sub>, in Federal waters, Gulf of Mexico (GOM), utilizing existing infrastructure, such as wells and pipelines and addressing regulatory, legal and technical issues.

## 5. Status

- The RCSPs span 43 states and 4 Canadian provinces and include agency participation from six member countries of the CSLF.
- 18 of the 19 geologic and 11 terrestrial field tests have been completed in the Validation Phase with one geologic field test remaining to be completed in 2012.
- The Development Phase has been underway since 2008, with eight anticipated large-scale projects currently being undertaken.
- The 2011 Regional Carbon Sequestration Partnerships Review Annual Review Proceedings, which include more detailed descriptions of status, are at:  
[http://www.netl.doe.gov/publications/proceedings/11/carbon\\_storage/index.html](http://www.netl.doe.gov/publications/proceedings/11/carbon_storage/index.html)
- U.S. DOE/NETL Carbon Storage R&D Project Review Meeting, Developing the Technologies and Building the Infrastructure for CO<sub>2</sub> Storage" will take place August 20<sup>th</sup>-23<sup>rd</sup>, 2012 in Pittsburgh, PA, U.S.. It will include updates to the RCSPs Development Phase Projects.

## 6. Links to RCSP Programmatic Information

- Carbon Storage webpage on the NETL website:  
[http://www.netl.doe.gov/technologies/carbon\\_seq/index.html](http://www.netl.doe.gov/technologies/carbon_seq/index.html)
- Carbon Sequestration Newsletter (distributed monthly):  
[http://www.netl.doe.gov/technologies/carbon\\_seq/refshelf/subscribe.html](http://www.netl.doe.gov/technologies/carbon_seq/refshelf/subscribe.html)
- DOE/NETL Carbon Storage Program: Technology Program Plan 2011:  
[http://www.netl.doe.gov/technologies/carbon\\_seq/refshelf/2011\\_Sequestration\\_Program\\_Plan.pdf](http://www.netl.doe.gov/technologies/carbon_seq/refshelf/2011_Sequestration_Program_Plan.pdf)
- DOE/NETL Carbon Dioxide Capture and Storage RD&D Roadmap 2010:  
[http://www.netl.doe.gov/technologies/carbon\\_seq/refshelf/CCSRoadmap.pdf](http://www.netl.doe.gov/technologies/carbon_seq/refshelf/CCSRoadmap.pdf)

- Carbon Sequestration Atlas of the United States and Canada:  
[http://www.netl.doe.gov/technologies/carbon\\_seq/refshelf/atlasIII/index.html](http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasIII/index.html)
- An Introduction to Carbon Capture and Sequestration (video):  
[mms://prod-mmedia.netl.doe.gov/carbon\\_sequestration\\_sept.wmv](mms://prod-mmedia.netl.doe.gov/carbon_sequestration_sept.wmv)
- Carbon Sequestration Program Environmental Reference Document:  
[http://www.netl.doe.gov/technologies/carbon\\_seq/refshelf/nepa/](http://www.netl.doe.gov/technologies/carbon_seq/refshelf/nepa/)
- Carbon Sequestration Project Portfolio:  
[http://www.netl.doe.gov/technologies/carbon\\_seq/refshelf/project%20portfolio/2010/index.html](http://www.netl.doe.gov/technologies/carbon_seq/refshelf/project%20portfolio/2010/index.html)
- Regional Carbon Sequestration Partnerships Phase I Accomplishments, see:  
[http://www.netl.doe.gov/technologies/carbon\\_seq/infrastructure/charefforts.html](http://www.netl.doe.gov/technologies/carbon_seq/infrastructure/charefforts.html)

**SaskPower Integrated CCS Demonstration Project at Boundary Dam Unit 3**  
 CSLF Project Status Report  
 April 2012

<b>1. Project Location:</b>
Project Location: SaskPower's Boundary Dam power site, Estevan Saskatchewan Canada
<b>2. Project Lead</b>
Lead project contacts: SaskPower, Michael Monea <ul style="list-style-type: none"> <li>• <a href="mailto:mmonea@saskpower.com">mmonea@saskpower.com</a></li> </ul>
<b>3. Project Objectives</b>
<ul style="list-style-type: none"> <li>• Rebuild a 45 year old 139 Mw power plant</li> <li>• Install a new 1,242 bn Cdn. 90% CO<sub>2</sub>, 100% SO<sub>2</sub>, capture unit</li> <li>• Make a commercial coal CO<sub>2</sub> capture unit have comparable lifecycle cost as a new Natural Gas Combined Cycle plant.</li> </ul>
<b>4. Recent Milestones</b>
<ul style="list-style-type: none"> <li>• Started construction May 1, 2011</li> <li>• Feb. 23, 2012, 40% finished construction of the capture unit</li> </ul>
<b>5. Status</b>
<ul style="list-style-type: none"> <li>• In construction, commissioning date 1<sup>st</sup> Quarter, 2014.</li> <li>• Negotiating sales contracts for CO<sub>2</sub> in the EOR industry</li> <li>• Will construct a deep saline reservoir storage site with the Petroleum Technology Research Centre near the Boundary Dam site</li> <li>• On time, on budget</li> <li>• Website:  <a href="http://www.saskpower.com/sustainable_growth/projects/carbon_capture_storage.shtml">http://www.saskpower.com/sustainable_growth/projects/carbon_capture_storage.shtml</a>.</li> </ul>

**Southeast Regional Carbon Sequestration Partnership (SECARB)**  
**Early Test at Cranfield Project**  
 CSLF Project Status Report  
 August 2012

<b>1. Project Location</b>
Test area is northeastern side of Cranfield Unit, 16 km east of Natchez Mississippi, USA
<b>2. Project Lead</b>
Susan D. Hovorka, Gulf Coast Carbon Center, Bureau of Economic Geology, Jackson School of Geosciences, the University of Texas at Austin <a href="mailto:susan.hovorka@beg.utexas.edu">susan.hovorka@beg.utexas.edu</a>
<b>3. Project Objectives</b>
<ul style="list-style-type: none"> <li>• History matching to compare model predictions of fluid flow to observed measurements of fluid flow in a complex rock unit.</li> <li>• Test the effectiveness of standard and innovating monitoring tools in the reservoir, above the reservoir, in the groundwater system, and in the shallow soil zone</li> <li>• This project is hosted by Denbury Onshore LLC; and field services are provided by Sandia Technologies LLC</li> </ul>
<b>4. Recent Milestones</b>
<ul style="list-style-type: none"> <li>• Four 2008-2012 years of monitoring has been completed</li> <li>• Data collected from time-lapse measurements after 1 year injection is in analysis. A clear response to CO<sub>2</sub> is observed in the down-dip part of the field where CO<sub>2</sub> has replaced brine. Signal from emplaced CO<sub>2</sub> is more variable in the regions that contained oil and gas.</li> <li>• 3.8 million metric tons CO<sub>2</sub> from Jackson Dome (natural source) have been stored</li> </ul>
<b>5. Status</b>
<ul style="list-style-type: none"> <li>• Post-injection 3-D seismic survey, VSP survey and cross well seismic survey, and cased hole logging has been completed with Lawrence Berkeley National Laboratory and Schlumberger as lead collaborators. CO<sub>2</sub> was imaged. Complex responses related to fluid complexity, and reservoir heterogeneity as well as data collection limitations are in assessment</li> <li>• Lawrence Livermore National Laboratory has documented the response of an Electrical Resistance Tomography array to a CO<sub>2</sub> flood</li> <li>• An in-zone geochemical monitoring program with Oak Ridge National Laboratory and USGS Menlo Park as major contributors has been completed. Geochemical response to CO<sub>2</sub> –rock-brine reaction is limited.</li> <li>• A near surface monitoring program has been conducted with University of Mississippi and Mississippi State University as major collaborators. Data collection continues. One small area, high amplitude surface anomaly, the “P Site” is undergoing intensive testing.</li> <li>• Project website; <a href="http://www.gulfcoastcarbon.org">www.gulfcoastcarbon.org</a>. See ‘bookshelf’ for reports.</li> </ul>

**Zama Acid Gas Enhanced Oil Recovery, CO<sub>2</sub> Sequestration, and Monitoring Project**  
 CSLF Project Status Report  
 August 2012

<b>1. Project Location</b>
Zama City, Alberta, Canada
<b>2. Project Lead</b>
<ul style="list-style-type: none"> <li>• Ed Steadman (<a href="mailto:esteadman@undeerc.org">esteadman@undeerc.org</a>)</li> <li>• Jim Sorensen (<a href="mailto:jsorensen@undeerc.org">jsorensen@undeerc.org</a>)</li> <li>• Charles Gorecki (<a href="mailto:cgorecki@undeerc.org">cgorecki@undeerc.org</a>)</li> <li>• Julie Gunderson (<a href="mailto:julie.gunderson@apachecorp.com">julie.gunderson@apachecorp.com</a>)</li> </ul>
<b>3. Project Objectives</b>
To validate the sequestration of CO <sub>2</sub> -rich acid gas in a depleted oil reservoir.
<b>4. Recent Milestones</b>
<ul style="list-style-type: none"> <li>• Laboratory work has continued with the following experiments:           <ul style="list-style-type: none"> <li>– Wellbore casing steels are being exposed for durations of 15 and 28 days to mixtures of CO<sub>2</sub> and H<sub>2</sub>S. Experiments are carried out at reservoir conditions analogous to Zama (2100 psi, 160°F). Analytical work is focused on deriving the nature and rates of degradation observed.</li> <li>– Rock samples are also being exposed under the same conditions to determine if mineralogical changes are observed. If observed, rates and quantification of change will be determined.</li> </ul> </li> <li>• Modeling and simulation have continued on the injection and production reservoir. This model will be used to better understand the sweep efficiency of the reservoir and to calculate the overall storage potential of this and similar pinnacles in the field.</li> <li>• Additional data has been acquired and is being analyzed for input into new static geologic models.</li> </ul>
<b>5. Status</b>
<p>As of May 2012, cumulative acid gas injected into the F Pool was 133,550 tons (CO<sub>2</sub> fraction – 93,485 tons), with net CO<sub>2</sub> stored of 40,357 tons.</p> <ul style="list-style-type: none"> <li>• Approximately 74,202 incremental barrels of oil has been produced using this technique.</li> <li>• At this time, Apache has shut down the gas plant, and plans for future oil field operations are ongoing.</li> <li>• Improved static geologic models of additional pinnacles are being developed and detailed dynamic simulations of injection and production will be conducted. The goal of these efforts is to develop improved estimates of OOIP, recoverable reserves, and CO<sub>2</sub> storage capacity for each of those pinnacles that have yet to be extensively researched.</li> </ul>

## Zero Emission Porto Tolle Project (ZEPT)

CSLF Project Status Report

September 2012

### 1. Project Location

Power plant owned by Enel Produzione and located in Porto Tolle, Province of Rovigo, Region of Veneto, 160 km south from Venice, Italy.

The CO<sub>2</sub> capture plant will be installed in Porto Tolle power plant, owned by Enel Produzione and located in the area of the Po river south bank (Po di Pila), approx 160 km south of Venice.

The separated CO<sub>2</sub> will be transported by a carbon steel pipeline, from an onshore pipeline terminal at Porto Tolle to an offshore injection platform through a subsea pipeline of about 100 km length.

The onshore terminal will be within the battery limits of the Porto Tolle power station. Regarding storage location, the pre-FEED studies have been based on a saline aquifer reservoir, located at around 25 km from the Adriatic coast.

### 2. Project Contact

- Mario Graziadio Enel Engineering and Research Spa  
[mario.graziadio@enel.com](mailto:mario.graziadio@enel.com)
- Cristiana La Marca Enel Engineering and Research Spa  
[cristiana.lamarca@enel.com](mailto:cristiana.lamarca@enel.com)

### 3. Project Objectives

The goal of the Porto Tolle Zero Emission Project is to demonstrate the industrial application of the CO<sub>2</sub> capture and geological storage in the power sector at full scale. The demo plant will be operated for an extended period (10 years) in order to fully demonstrate the technology on an industrial scale, access clearly the real costs of CCS and provide a commercial solution for new installations after 2020. The project is intended to prove the retrofit option for high-efficiency coal fired units which will be built (or replaced) in the coming 10-15 years.

This activity will be performed through:

- the design, procurement and construction of the demonstration CCS plant as well as all the detailed site characterisation aimed at verifying the feasibility of the injection and storage of CO<sub>2</sub> in a safe and detectable manner
- identification of the specific technical solutions for the whole CCS chain
- identification of the permitting procedures
- R&D activities related to CO<sub>2</sub> capture, that will allow to assess the environmental impact, the performances
- development of CCS public acceptance

### 4. Recent Milestones

- Realization, start-up and testing of a CO<sub>2</sub> capture pilot plant (10.000 Nm<sup>3</sup>/h)
- Storage site selection and detailed characterization, feasibility study of injection well and platform
- Development of FEED studies for CCU (Carbon Capture Unit) technology

## 5. Status

- The overall progress of the conversion to coal firing of Porto Tolle power plant has been affected by the Decision of the Council of State, that partially voided the Environmental Authorization.
- The impact of the issue on both the Porto Tolle conversion to coal firing and on CCS permitting procedure is currently under assessment.
- The impact on the CCS project concerning the dispute over the permit for the base power plant, is still being analysed by the project team. The updated timetable is currently under assessment.