Carbon Sequestration Leadership Forum
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CSLF-T-2012-02
07 May 2012

TECHNICAL GROUP

Draft Report from Task Force to Assess Progress on Technical Issues Affecting CCS

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DRAFT REPORT FROM TASK FORCE TO ASSESS PROGRESS ON TECHNICAL ISSUES AFFECTING CCS

Note by the Secretariat

Background

The CSLF Task Force to Assess Progress on Issues Affecting CCS was formed at the March 2010 Technical Group Meeting in Pau, France and consists of four Working Groups:

- Working Group on Capture (chaired by the United States)
- Working Group on Transport and Infrastructure (chaired by the Netherlands)
- Working Group on Storage (chaired by Canada)
- Working Group on Integration (chaired by the Global CCS Institute)

The original objective of the Task Force was to complement the Project Interaction and Review Team's (PIRT's) assessment of the CCS readiness of the 30 CSLF-recognized projects. Subsequently, at the March 2011 PIRT meeting in Al Khobar, Saudi Arabia, there was agreement that this new Task Force should abandon the CCS readiness assessment and instead concentrate on assessing technology-related issues that affect CCS.

This Draft Report is a summary of the Task Force's activities and outcomes.

Action Requested

The Technical Group is requested to review and approve this Draft Report.

Carbon Sequestration Leadership Forum

A Draft Report to the Technical Group:
Task Force to Assess Progress on Technical Issues Affecting CCS.

Contributors

Draft Report – Clinton Foster, Chris Consoli

Working Groups

Capture – George Guthrie

Transport and Infrastructure – Chris Consoli

Storage and Monitoring – Stefan Bachu and Lars Ingolf Eide

Integration – Klaas van Alphen

BACKGROUND

The Task Force to *Assess the progress on closing technology-related gaps that affect the deployment of CCS* was established by the CSLF Technical Group (TG) on recommendation by the CSLF Projects Interaction and Review Team (PIRT) at the PIRT meetings in Canberra (1-3 February 2010) and Pau (15 March 2010). The objective of the Task Force was to complement the PIRT's assessment of the CCS readiness of the 30 CSLF-recognized projects. An outcome of the PIRT meeting in Al Khobar (3 March 2011) was the decision to abandon the CCS readiness assessment, but continue with the assessment on closing technology-related gaps. It was also agreed by the Technical Group (TG) that the word 'gaps' be replaced by the term 'issues'.

The Task Force was renamed to *Assess Progress on Technical Issues Affecting CCS.*

The Task Force elicited an initial response from 42 members from 14 countries, including stakeholders, IEAGHG and GCCSI (Figure 1). Following the TG meeting in Edmonton (18 May 2011), membership was later revised by the Working Group Chairs to focus on technical expertise, with the full knowledge and intent that the findings of the Working Groups would be made publicly available.

The Task Force, chaired by Clinton Foster, Australia, comprises four Working Groups:

- Capture Technologies: chaired by George Guthrie, USA
- Transport and Infrastructure: chaired by Chris Consoli, Australia
- Storage and Monitoring: chaired by Stefan Bachu, Canada
- Integration, from project proposal to implementation: developed in cooperation with, and reported by the Global CCS Institute.

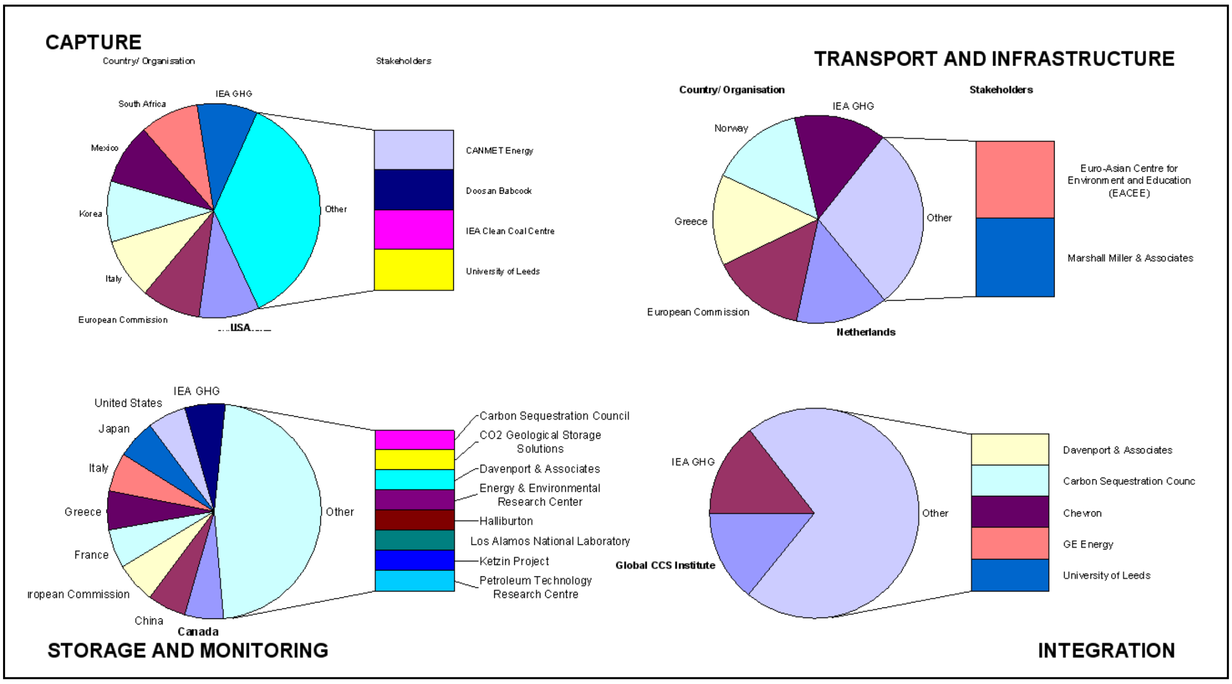

Figure 1. Task Force and Working Group Members (C. Foster. 2010. CSLF Meeting, Warsaw, Poland)

Through consultation between specialists within the Working Groups, technical issues affecting the value chain of CCS have been assessed. This was achieved through initially analysing the major technical issues in CCS technologies, from capture through to storage, both in the R&D and commercial realms. Following this initial study, the focus of further assessments by the Task Force centred on the CSLF-recognised projects. The aim was to identify which projects were, or were not, addressing the issues originally identified. The results have drawn attention to the progress which has been made on the existing technical issues in CCS as well as identifying new technological issues which have emerged (see below). Five major recommendations of the Task Force include:

1. That future CSLF Task Forces within the TG should focus on technical issues affecting large-scale deployment rather than R&D issues.

2. The CSLF should focus on large-scale (>1mtpa) integrated projects as a primary standard, although pilot projects championing new technologies of the CCS chain should also be incorporated and sought by the TG for CSLF recognition.

3. CCS for emissions-intensive industries should be a key focus (eg. cement and steel production), because CCS is the only viable method for reducing emissions at scale.

4. The CSLF TG should focus on, and support the, distribution of knowledge, guideline and best practices to CSLF Projects. This should be seen as a key objective of the CSLF and through a Task Force utilise the expertise/findings of other organisations (e.g., GCCSI and IEAGHG).

5. In addition to technical issues, the Policy Group needs to focus on public acceptance and international regulation/ agreements of CO_2 transport and storage as these are viewed as major hurdles to the rapid deployment of CCS.

The findings will inform updates of the Technical Roadmap (TRM, CSLF 2011), Strategic Implementation Report, and Project submission forms. Recommendations are summarised below and contained within the individual completed Working Group reports (attached as Appendices A-D).

At the time of submission of this Report, the Capture WG had not yet completed a full report, but a technical analysis checklist was completed (Appendix A). Some recent findings from other, non-CSLF studies, are included for CO_2 capture summary.

SUMMARY OF CHALLENGES AND RECOMMENDATIONS FROM THE WORKING GROUPS

CAPTURE

Challenges

- CO_2 capture and compression is currently the most costly component of CCS (Figure 2). Feron and Paterson (2011) identified the costs of capture within the full CCS chain and identified that capture with compression will cost between \$70 -90 tonne CO_2, transport and storage will cost an additional \$10-50 tonne CO_2, with an overall range of \$80 – 140 tonne CO_2 (although originally given in Australian \$, A\$1~ USD 1). Note: Evidence from advanced storage projects show that the geological storage costs are much greater than detailed below when considering the entire injection program (e.g., when including well remediation).

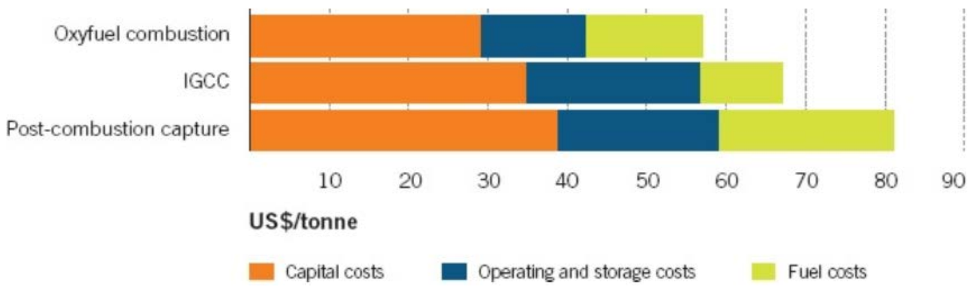

Figure 2. Cost of CO_2 avoided for three major capture technologies (GCCSI, 2011) for coal-fired power generation.

- Although CO_2 capture is common-practice in the natural gas industry, to separate CO_2 (and other impurities) for sales gas, many CCS capture projects are at pilot R&D or lab scale, therefore there is a need for large scale (>1mtpa) capture projects from power plants and other industries, mainly steel and cement manufacturing.

    - The upscaling, energy penalty, environmental impact, and improving the purity of the CO_2 stream are the major technological challenges. Specifically in upscaling, the areas include:
        - Design, cost, and space requirements, operation and integration of CCS with plant facilities.

WG Analysis Findings (with TRM data)

- The majority of CSLF-recognised projects are focussed on, or have a significant component of, capture technologies. However, the CO_2 capture industry is rapidly evolving and new projects should be regularly evaluated to ensure up-to-date technological advancement of capture within the CSLF.
- The rapid evolution of the CO_2 capture industry has resulted in a large number of issues being identified. Many of these are not being, or are poorly, addressed (i.e, only by 1-2 projects). The majority of the issues relates to pre-combustion capture, oxyfuel combustion, novel technologies (e.g., enzyme, cryogenic, or hydrate-based technologies), and interestingly CO_2 compression. In these areas of capture, only one or two projects are addressing the issues related to capture technologies. This probably reflects the embryonic stage of the commercialisation of these technologies to capture CO_2.
- Capture from non-power industrial processes is the focus of four CSLF projects, but they are mostly confined to LNG/EOR/ petroleum production, where capture is part of the operation. It does not reflect ongoing progress of capture in industrial processes such as cement and steel manufacturing.
- The general issues related to advancement of CCS in the capture technology include:
    - Prove technologies at full scale for power plants;
    - Reduce energy penalty through optimized process design and research into improved and novel capture technologies;
    - Generate knowledge that is necessary to validate CCS for bio-power, including exploration of use of existing and new capture technologies and evaluate process efficiencies, economics and HSE aspects; and
    - Build understanding of new capture systems by acquiring pilot scale data (2-4 MW).

Findings** **(from GCCSI-Global Status of CCS, 2011

The GCCSI report mirrors that of the WG and TRM, with three principal findings:

- A need to construct and operate commercial-scale facilities with carbon capture to demonstrate the host power generation technology integrated with capture.
- CO_2 specifications and the impact of impurities.
- R&D focused on improvement of component performance.

There are also a series of more detailed challenges:

- Increase efficiency of the basic technologies of PCC and combustion (gas) turbines.
- Pre-combustion capture - improve the CO-shift and CO_2-capture with new adsorption media, new catalysts and by optimising process integration.

- Post-combustion capture - improve solvents through catalysts and chemical modifications to improve loading efficiency, solvent loss and environmental impacts.
- Oxyfuel combustion - more efficient cycles and reduction in the energy penalty for oxygen production.

WG Recommendations

- No recommendations were submitted from the working group.

TRANSPORT AND INFRASTRUCTURE

Challenges

- Although, the technology and infrastructure required for transportation of CO_2 is common practice worldwide and the transportation of CO_2, either via pipeline or tanker (ship, road, and rail) is a mature technology; the challenges for CCS are:
    - Hub and spoke network (multiple-sources, compositions, rates of flow, etc); and
    - Up-scaling of the infrastructure and transport technology required for large-scale, commercial projects.
- Policy and legislative developments (not considered further).

WG Analysis Findings

- 8 CSLF Projects have a component which focuses on transport and/or infrastructure as part of study which also included non-CSLF projects. However, all integrated projects, as well as projects with a storage focus have, in their nature, a transport component and hence will be also addressing key issues of transport; information which could become available to the CSLF, if required.
- All projects addressed infrastructure technical issues; however, for the scope of this analysis, only pilot to large-scale projects were evaluated for infrastructure technology issues.
- The broad issues, detailed below, follow the general nature of the CO_2 transport and infrastructure industry:
    - Effect of impurities in the CO_2 stream on all components of the transport infrastructure;
    - Effect of supercritical CO_2 as a solvent on all components of the transport infrastructure, in particular sealing material; and
    - Research into pipeline incidents (leaks, fractures, effects and impacts) and CO2 dispersion modelling in case of leakage.

WG Recommendations

- The WG recommends that the effect of impurities in the CO_2 stream on transport infrastructure should be the focus of future Task Forces and Project candidates.
- Safety practices and an understanding of risks, including pipeline incidents, associated with the transport of compressed gas should also be the focus of future Task Forces and Project candidates.

    - Several non-CSLF Projects are currently addressing these two technology-related issues and should be approached (see Appendix C).
- It is important that knowledge and learnings are shared with the CSLF Membership and this should form an integral part of the Technical WG and a future Task Force.
- The Policy Group should examine relevant litigation hurdles yet to be overcome, such as the London Protocol (Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter), allowing the trans-boundary transportation for CO_2 storage purposes.

STORAGE AND MONITORING

Challenges

- Large scale storage is taking place and larger projects are under construction;
    - Generally site specific challenges are the major technical issues faced.
- There are non-technical issues related to the storage technology, which are viewed as major hurdles to any project; both of which have previously stopped the progress of entire CCS projects, including:
    - Public acceptance of storage, especially onshore; and
    - Lack of international regulation and agreements of CO_2 storage in marine environments.

WG Analysis Findings

- The WG identified 25 CSLF projects, which had a storage and monitoring component to their project.
- Through several detailed analyses and concerted effort by the WG, currently, the following issues are either poorly addressed or not being addressed at all:
    - Storage in unconventional media (coals, shales, basalts);
    - Enhanced in-situ mineral trapping and mineralization;
    - Storage engineering for pressure and CO_2 plume control;
    - Monitoring technologies and leakage detection;
    - Effects, risks and remediation of leakage;
    - Site management;
    - Consolidation of various guidelines and “best practices” manuals; and
    - Outreach, addressing public concerns, and educating the public and decision makers (political, regulatory, industry).

WG Recommendations

- Two major issues are not being addressed and the WG recommends that they should be focus for future Storage and Monitoring Task Forces and Project candidates:
    - Development of guidelines; and
    - Storage media other than deep saline aquifers.
- The majority of projects are addressing technical and deployment issues, not scientific issues and this should be reflected in the Project Recognition Questionnaire. Thus it is recommended that the Questionnaire be modified to

focus on technical and deployment issues rather than the existing largely scientifically-based issues.
- The CSLF Technical Group should refocus its attention and activities in the next 5-10 years on implementation and deployment issues.

INTEGRATION (lead by GCCSI)

Challenges

- The GCCSI (including Institute Member and CSLF Projects), which focuses on facilitating collaboration and knowledge sharing, has already undertaken several studies regarding integration, and achievements include:
    - The development of a generic CCS project development framework, including all activities/task to be undertaken in each stage of a CCS project for each CCS component;
    - Publication, together with American Electric Power (AEP), of 'an Integration report' on AEP's Mountaineer project; and
    - Ongoing work with advanced projects, such as ROAD (Netherlands), Trailblazer (US), GETICA (Romania) and Pioneer (Canada) to make available the learnings from their FEED/Feasibility processes.
- The GCCSI/CSLF WG has identified that the major technical challenge with the CCS chain is the integration of each of the components at a large, commercial scale, and few projects are properly addressing this issue.
- In the early stages of the CSLF, Projects were largely single component based, either capture or storage. However, recently integrated projects, from pilot to commercial scale are receiving CSLF recognition and addressing the issues of integration, which lie largely in three principal areas:
    - A balance between plant operation (outflows, peak production, etc) and integration;
    - Various sectors and industries coming together and working together despite different design and operation philosophies; and
    - Identifying adequate storage at the start of a project.

WG Analysis Findings

- The WG has undertaken a rigorous study incorporating both CSLF and non-CSLF projects (Institute Members) and a workshop of commercial scale project operators was held to identify key integration issues. In summary it was identified that more work is required in the areas of:
    - Integration/regeneration of plant heat (and cooling) in the CO_2 capture process;
    - Integration of environmental control systems (SOx, NOx, and CO_2 removal);
    - Improvement of options for operational flexibility, while ensuring CCS system reliability;
    - Impacts of CO_2 stream composition and impurities for CCS operations (in particular for transportation systems); and
    - Understanding the scale-up risks of CO_2 capture processes.

WG Recommendations

- The focus of the CSLF TG and Project candidates should be on the first large scale CCS demonstration plants in the power sector and thus:
  - Making CCS work at scale; and
  - To strike the right balance between plant operation and integration.
- The CSLF should facilitate intensive collaboration and communication between the various entities involved in the project.
- Development of a practical, generic CCS project management handbook to highlight key integration issues and associated risks and provide guidance on how they could be addressed.
- For Project candidates, the CSLF should focus on the following two aspects of integration:
  - First steps to any project should be to secure a CO_2 sink (i.e. storage adequately defined (identified, characterised and possibly permitted) before commencing on a capture FEED study.
  - Invest more heavily on the front end of the project (front end loading [FEL]) in order to mitigate risks and cost escalations at a later stage in the project.

CSLF GOVERNANCE RECOMMENDATIONS

1. Nomenclature

1.1 The Task Force reaffirms the importance of using the term *issues*, instead of *gaps*, affecting CCS. Equally important is the term progress – which denotes activity seeking solutions.

1.2 CSLF Project Submission Form and CSLF Gaps Analysis Checklist (GAC):

i. Project Recognition Questionnaire should be simplified.

ii. Gap Analysis Checklist (GAC) should be simplified and synchronized with the checklist of the Technical Roadmap (TRM).

iii. A more granular, detailed Gap Analysis Checklists, as defined by two of the Working Groups, should be utilised. But given that there are limited resources, identified issues are time bound, and that other agencies (such as the Global CCS Institute) undertake annual reviews of progress; the most effective use of these data is to provide them to those relevant bodies undertaking analyses of progress.

ACKNOWLEDGEMENTS

I would like to thank the WG Chairs and their Members for their active participation in this Task Force. In particular, I acknowledge the work of the GCCSI working with the CSLF on their Integration Theme and providing results to this Task Force; also thanks to Research Council of Norway for making available the expertise of Mr Lars Ingolf Eide; and finally thanks to Dr Consoli who compiled the draft of this report.

Clinton Foster

Task Force Chair

12 April, 2012

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1. CSLF Technology Roadmap 2011. CSLF Publication. www.cslforum.org/.../CSLF_Technology_Roadmap_2011.pdf

2. Feron, P and Paterson, L. 2011. Reducing the costs of CO2 capture and storage (CCS). CSRIO Report. http://www.csiro.au/Outcomes/Energy/reducing-CCS-costs.aspx

3. Global Status of CCS. 2011. Global CCS Institute Publication (See Figure 3.1) http://www.globalccsinstitute.com/publications/global-status-ccs-2011/online/26886

APPENDIX A. CAPTURE REPORT-

CSLF Technical Issues Analysis Checklist

Capture Technologies

As of 30 March 2012, the Capture WG had completed the following technical analysis checklist, based on responses from 15 of the 35 CSLF identified projects, 6 of which did not address any capture gaps.
A complete report from the Capture WG was not available but some findings based on the references listed at the end of the main report were included.

Technical Issue #	General	# of Projects addressing this issue
1	Development and application of power plant concepts to integrate CO_2 capture	2
2	Development and application of power plant with CO_2 capture (flexibility, operability, control)	3
3	Power plant and CO_2 capture integration and heat recovery	2
4	Development and application of new capture process engineering concepts (flash units, high/low pressure regeneration, vapor compression, split flow, etc.)	2
5	Creation of a full scale capture plant risk analysis (technical, financial, emissions, etc.)	2
6	Advance integration and optimization of components for power station applications	1
7	Capture from non-power industrial processes	4
8	Development of capture systems for NGCC power plants	3
9	CO_2 purity standards for transport and injection (most applicable to oxy-combustion)	3
	Air Separation	
10	Cryogenic air separation	1
11	Ion transport membrane technologies for air separation	
12	Oxygen transport membrane technologies for air separation	

	Post-Combustion Capture	
13	Improved solvent systems	3
14	Advanced chemical solvents that have lower regeneration heat duties	2
15	Improvement in chemical sorbent characteristics	1
16	Advance organic / inorganic non-precipitation absorption systems	1
17	Identify advantages and limitations of precipitating systems (e.g., carbonates)	1
18	Improved process contactors (membranes, packing materials)	2
19	Advanced solid sorbent systems	2
20	Development of highly selective and permeable membrane systems designed for low partial pressure, post-combustion flue gas streams	
21	CO_2 capture pilot plant	3
22	Fully integrated demonstration plant	3
23	Optimize capture process systems to reduce power stations energy loss	2
24	Optimize capture process systems to reduce power stations environmental impact	2
25	Develop better understanding of the assessment of environmental impacts of capture technologies	2
	Pre-Combustion Capture	
26	Develop high efficiency and low emission H_2 gas turbines	1
27	Water-gas shift membrane reactor	1
28	Absorption-enhanced water-gas shift reactor	
29	Improve physical solvent separation process at higher pressure	
30	Improve physical solvent selectivity to improve H_2 losses	

31	Improve physical solvent CO_2 loading at higher temperature	
32	Research into a chemical solvents that utilizes a combination of thermal and pressure swing regeneration too efficiently separate CO_2 from syngas while maintaining pressure	
33	Advance solid sorbent systems	
34	Improvement in membrane selectivity and permeability	
35	Improve membrane stability and durability (hydrothermal, thermal, chemical, physical)	1
36	Optimize membrane process design and integration within the IGCC power cycle	
37	Enhance fuel flexibility - Coal and liquid petroleum gasification, natural gas reformer, syngas cooler	
38	CO_2 capture pilot plant	1
39	Fully integrated demonstration plant	1
40	Optimize capture process systems to reduce power stations energy loss	1
41	Optimize capture process systems to reduce power stations environmental impact	
42	Develop better understanding of the assessment of environmental impacts of capture technologies	
	Oxyfuel Combustion	
43	Development and application of advanced boiler design	1
44	Development and application of oxy-fuel gas turbines	
45	Improved knowledge of oxy-combustion science	2
46	Development and application of high temperature turbines	
47	Development and application of CO_2/N_2 separation technology for industrial processes	

48	Research into advanced material selections	
49	Development and application of CO_2 purification process (final product conditioning process)	
50	Improve applications to address other emissions (NO_X, SO_X, metals)	
51	CO_2 capture pilot plant	1
52	Fully integrated demonstration plant	
53	Optimize capture process systems to reduce power stations energy loss	
54	Optimize capture process systems to reduce power stations environmental impact	1
55	Develop better understanding of the assessment of environmental impacts of capture technologies	
	Emerging and New Concepts for CO_2 Capture	
56	Research into post-combustion carbonate looping cycles	1
57	Research into chemical looping combustion	2
58	Research into chemical looping gasification	
59	Research into ionic liquids (IL)	1
60	Research into enzyme technology	
61	Research into cryogenic based technologies	
62	Research into hydrate based technologies	
	Initial CO_2 Compression	
63	CO_2 compression utilizing intra-stage cooling	1
64	Refrigeration to liquefy CO_2 and pressure increase using cryogenic pump	
65	Supersonic shock wave compression technology	

APPENDIX B.

TRANSPORT AND INFRASTRUCTURE REPORT

2011 Report of Transport and Infrastructure WG

Members

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Background

Transport and Infrastructure Working Group (herein Transport WG) formed to review the technical issues (gaps) of the Technical Road Map (TRM). The WG also updated the Project Submission form for CSLF recognition, which is currently ongoing.

Introduction

The long-distance transport of large quantities of substances (i.e. LNG, oil, CO_2, water) over a wide range of environments is common practice worldwide. Moreover, the transportation of CO_2, either via pipeline or tanker (ship, road, and rail) is a mature technology for the EOR and Food/Beverage industries, which generally consists of a single source and composition of CO_2 with direct source to user transport (see Doctor et al. 2005). However, special design considerations will be required for the CCS industry, especially given the potential complexity of the hub and spoke network (multiple-sources, compositions, rates of flow, etc). A second major challenge is seen in the upscaling of the infrastructure and transport technology required for large-scale, commercial projects, as well as the associated policy and legislative developments.

Addressing Issues of Transport and Infrastructure

Overall, the Transport WG is well advanced in the identification of issues and addressing them through CSLF-Projects due to the maturity of the transport industry and limited need for new technology. Hence, the expertise, best practices and standards are routine and novel issues that have arisen in the capture and storage technologies are not apparent at this point for the CCS transport component. CSLF-Projects which address issues within Transport are either in the advanced, active or completed categories:

1. CCS Rotterdam (ROAD) (Active)
2. Lacq CO_2 Capture and Storage Project (Active)
3. Geologic CO_2 Storage Assurance at In Salah, Algeria (Active)
4. Regional Carbon Sequestration Partnerships (Active)
5. CANMET Energy Technology Center R&D Oxyfuel Combustion for CO_2 Capture (Active)
6. Dynamis (Completed)
7. CO_2STORE (Completed)
8. IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project (Active)

Progress on Addressing Issues of Transport and Infrastructure

Technical Roadmap 2011		CSLF-PROJECT	Example Non-CSLF Project
▪ Conduct cost-benefit analysis and modeling of CO_2 pipeline networks and transport systems for tankers and trucks		All	Chiyoda Corporation Study, 2011
▪ Issues related to the composition of the gas transported in pipelines:	Develop detailed specification with respect to the impurities present from various processes (power station, refineries, industry), which are not present in current CO_2 production units	1, 5, 6	
	Acquire experimental thermodynamic data for CO_2 with impurities (H_2, SOx, NOx, H_2S, O_2, methane, other hydrocarbons etc), develop improved equations of state and establish phase diagram database for the most likely compositions of the CO_2 stream to be transported		
	Understand the effects impurities may have on CO_2 compression and transport, including evaluation of corrosion potentials	1	CO2Europipe
	Gain experience and develop flow models for dense CO_2 streams in pipelines, including depressurization	1, 3	CO2Pipetrains
	Understand the effects of supercritical CO_2 as a solvent on sealing material (e.g., elastomers in valves, gaskets, coatings and O-rings)		
▪ Conduct further research into leaks and running ductile fractures to improve understanding of the effects and impacts of a burst in the pipeline, including experiments and model development			CO2Pipetrains
▪ Improve dispersion modeling and safety analysis for incidental release of larger quantities of CO_2 from the transport system, including the marine setting (e.g., CO_2 pipeline, CO_2 ship, other land transport or intermediate storage tank at harbor)			Kingsnorth E.ON
▪ Develop proper mitigation measures and design, to ensure safe establishment and operation of CO_2 pipelines through densely populated areas		1	CO2Europipe
▪ Identify and define proper safety protocols for CO_2 pipelines, including response and remediation		1, 6	
▪ Update technical standards for CO2 transport as new knowledge become available		n/a	n/a

CSLF Recognised Gaps 2010 Study	CSLF-PROJECT
Cost benefit analysis and modeling of CO_2 pipeline and transport systems	1, 2, 6, 7
Tanker transport of liquid CO_2	1, 6
Specifications for impurities from various processes	1, 5, 6
Dispersion modeling and safety analysis for incidental release of large quantities of CO_2	1
Safety and mitigation of pipelines through urban areas	1, 4, 6
Safety protocols to protect CO_2 pipelines, including response and remediation	1
Identify regulations and standards for CO2 transport	1, 6

Advances in Transport and Infrastructure in 2011

1. Policy and Standards

Major legislative arrangements and standards have been addressed for the transport of CO_2. However, only Norway has ratified the amendment to Article 8 of the London Protocol (Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter), allowing for the export of CO_2 streams. Thus the trans-boundary transportation for storage purposes remains proscribed under the Protocol. However, under the OSPAR Convention (Convention for the Protection of the Marine Environment of the North-East Atlantic) amendment for the storage of CO_2 in geological formations under the seabed has been ratified since 2011. The IEA GHG has started a process to identify how trans-boundary CO_2 transport can be performed now and until the London Convention has been ratified by the required number of members.

Cost effective CCS will require trans-boundary transportation and shared pipeline networks. Availability of large storage sinks suggests there will be a requirement for early and close cooperation of different industries and government at all level (GCCSI, 2011). Strategic planning to reduce the long term costs, due to the large scale of CCS, was identified as a vital hurdle to overcome, along with the development of clusters, over-sized pipelines and cross-border restrictions removed. Finally, the scale of CCS transport infrastructure will rival the hydrocarbon industry and thus an efficient legislative and regulatory system must be in place by 2030 at the latest (ZEP, 2011).

Early planning of infrastructure for linking sources and sinks is essential to ensure early deployment of CCS. One example is Northern Europe where there is a huge storage capacity in the North Sea. Developing transport infrastructure for the North Sea would accelerate CCS deployment, especially given that there is low public acceptance for onshore storage; a hurdle for CCS in many countries. Such infrastructure should be planned and built large enough to include all larger CO_2 sources in countries close to the North Sea.

2. Technical

Pipeline

According to the Global Status of CCS report (GCCSI, 2011), overall it appears that the construction of infrastructure required for the transportation of CO_2 at a commercial scale is large, especially in the 2020-2030 timeframe. However, it is modelled that the construction of pipeline in Europe, which requires 2,300km by 2020 and 22,000km by 2050, and the United States (8,000-21,000km by 2020; 35,000-58,000km by 2050) is achievable. The scale and cost of the transport of CO_2 will mean it will become an important industrial sector. Both the pipeline and shipping industries are mature, but scale and costs are the major burden.

Clusters proximate to a CO_2 source is identified as a significant step to reduce costs (reduction of over 25% of expenditure), which can be achieved through the participation of multiple stakeholders, speeding up deployment and connecting smaller emitters. Issues relating to hub pipelines include the large diameter pipes required and variation of gas composition from different emitters. The GCCSI have identified two hubs in Australia (Collie, Western Australia and CarbonNet, Victoria), which will use hub-style pipeline design. In Europe the two identified clusters (Rotterdam, Netherlands; South Yorkshire-Humber region, UK) both incorporate a small region of intense major carbon emitting sources with access to depleted fields and reservoirs of the North Sea. The design of both projects will incorporate pipeline and possibly shipping logistics and may incorporate EOR. In Canada the Alberta Carbon Trunk Line is a pipeline development funded partly by the Government of Alberta, which focuses on collecting CO_2 sources for use in EOR in central Alberta.

The ZEP (2011) study is a comprehensive analysis on the economics and feasibility of transport costs in CCS. Results are shown in Tables below. The cluster network of emission sources to storage sites is identified as the most cost effective method. The base case for all assumptions was 20Mtpa capacity. Overall, pipeline costs are mainly CAPEX (>90%) and costs are proportional to distance. Shipping has less CAPEX (<50%) as distance is a small factor to overall costs. It was identified that combining pipe and ships in offshore hub networks are lower risk and cost effective. For example, in the early period during pipeline construction, shipping could provide the major initial transport means.

Although pipeline CO_2 transport has been active in North America for decades, it is important to solve issues related to impurities in the CO_2 stream. Transporting near-pure CO_2 is not challenging, but CO_2 captured from power plants could have impurities at ppm levels that can cause challenges. If small amount of water is present the impurities can cause corrosion, or they can lead to precipitation of solids that could clog the injection well.

Shipping

Design work on larger CO_2 carrier vessels is underway in Norway and Japan, focussing on designs comparable to semi-refrigerated LPG carriers (GCCSI, 2011).

The CO2Europipe project suggests shipping will be important during the start-up process of a CCS project, not only due to quick start up, but also enables fluctuating volumes of CO_2, and can target small offshore and remote fields. However, these fields need a relatively high injection rate to reduce the turn around time of shipping (Neele et al. 2010). Furthermore, shipping is more cost effective with increasing distance form source to sink and enables the sourcing of several hubs to different sinks.

A feasibility study by the Chiyoda Corporation and the University of Tokyo on a CO_2 carrier for ship-based CCS was conducted where a ship connects directly to injection points without a platform (Chiyoda, 2011). The focus of this preliminary study was an in depth analysis on the regulations, logistics and technical aspects of bulk CO_2 ship-based carriers and supporting infrastructure, including ship times, loading and unloading facilities, and injection design.

The design model focused on a LNG-style ship with injection facilities. It is concluded that ship-based transport is cost-effective for long distances, or where there is uncertainty in matching the scales of source to sink. In the latter, a series of small to medium sized ships prove feasible. Finally, in terms of economics, where intermediate storage is required, ship-based is the best option. The study identified that all the components of transport and associated infrastructure are present; however the complete system will be a new technology (Source: Chiyoda, 2011).

The ROAD project is one of the more advanced studies completed (Tetteroo et al. 2011). It combines a CO_2 Hub, comprising power generation (pre- and post-combustion capture) and industrial including refinery and hydrogen production within the Port of Rotterdam. It will involve onshore pipelines to a central hub (intermediate storage site), whereby offshore pipelines and shipping will transport CO_2 to offshore storage sites (depleted fields). The key points of the ROAD study for this review is a focus on multiple source, multiple sink, but single intermediate hub system and that ship transport will be used over long distances (>150-200km).

Short-term resolutions to be reached

1. Complete Technical Roadmap Gaps and identify Projects (both CSLF and non-CSLF) which address the gaps.
2. Confirm the new version of gaps analysis checklist for the CSLF-Project Submission or retain previous version (see below).
3. Confirm the incorporation of CO_2 compression, both at the capture facility and downstream, within the Transport WG (from CSLF TG Minutes, Beijing: CSLF-T-2011-08)
4. Confirmation of a CSLF Workshop focusing on Transport and Infrastructure.
    CSLF TG Minutes, Beijing: "Vice Chair Tony Surridge noted that South Africa plans to have a workshop on transportation towards the end of 2012, in October or November. He suggested that it would be another opportunity to hold a CSLF workshop on CO_2 transportation in conjunction with this meeting." CSLF-T-2011-08.
5. Confirm Transport and Infrastructure WG under the Technical Issues. The Task Force will also address goals of Action Plan 5: CO_2 Compression and Transport Milestones (CSLF Beijing).

Plan: The Technical Group will review technologies and assess pipeline standards for CO_2 transport, in particular in relation to impurities in the CO_2 stream. Issues such as thermodynamics, fluid dynamics, and materials of construction, will be considered. Alternatives to pipelines, such as ship transport, will also be assessed.
Technical Barriers: Lack of CO_2 Transport infrastructure
Outcomes: Identification of optimum technical CO_2 transport strategies, both for pipeline and non-pipeline alternatives. Assessment of purity issues as they apply to CO_2 transport. Identification of optimal compression options and alternatives.

i. CO_2 transport workshop- TBD 2014
ii. Interim Report TBD 2015
iii. Final Report TBD 2016

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7. ZEP (European Technology Platform for Zero Emission Fossil Fuel Power Plants), 2011. The costs of CO_2 capture, transport and storage. [online] Available at: www.zeroemissionsplatform.eu/library/publication/165-zep-cost-report-summary.html [Accessed 29 July 2011].

Technical Issues (Gaps) Tables

Technical Roadmap Priority Activities (2011)

<table>
<tr><td colspan="2">▪ Conduct cost-benefit analysis and modeling of CO_2 pipeline networks and transport systems for tankers and trucks</td></tr>
<tr><td rowspan="5">▪ Issues related to the composition of the gas transported in pipelines:</td><td>Develop detailed specification with respect to the impurities present from various processes (power station, refineries, industry), which are not present in current CO_2 production units</td></tr>
<tr><td>Acquire experimental thermodynamic data for CO_2 with impurities (H_2, SOx, NOx, H_2S, O_2, methane, other hydrocarbons etc), develop improved equations of state and establish phase diagram database for the most likely compositions of the CO_2 stream to be transported</td></tr>
<tr><td>Understand the effects impurities may have on CO_2 compression and transport, including evaluation of corrosion potentials</td></tr>
<tr><td>Gain experience and develop flow models for dense CO_2 streams in pipelines, including depressurization</td></tr>
<tr><td>Understand the effects of supercritical CO_2 as a solvent on sealing material (e.g., elastomers in valves, gaskets, coatings and O-rings)</td></tr>
<tr><td colspan="2">▪ Conduct further research into leaks and running ductile fractures to improve understanding of the effects and impacts of a burst in the pipeline, including experiments and model development</td></tr>
<tr><td colspan="2">▪ Improve dispersion modeling and safety analysis for incidental release of larger quantities of CO_2 from the transport system, including the marine setting (e.g., CO_2 pipeline, CO_2 ship, other land transport or intermediate storage tank at harbor)</td></tr>
<tr><td colspan="2">▪ Develop proper mitigation measures and design, to ensure safe establishment and operation of CO_2 pipelines through densely populated areas</td></tr>
<tr><td colspan="2">▪ Identify and define proper safety protocols for CO_2 pipelines, including response and remediation</td></tr>
<tr><td colspan="2">▪ Update technical standards for CO2 transport as new knowledge become available</td></tr>
</table>

Summary of Technical Roadmap Priority Activities (2011)

Element: Transport R&D	
Need	**Gaps**
Create the ability to optimize transport infrastructure to accept CO_2 from different sources, to ultimately reduce the risks and high costs	**Pipeline transport** ▪ Better understanding of the behaviour of CO_2 with impurities and the effects on CO_2 transport ▪ Response and remediation procedures developed in advance of the possibility of CO_2 pipeline accidents **Infrastructure planning** ▪ Better modeling capability of transport network of CO_2 between sources and potential sinks, including compression and optimization

CSLF-Project Submission Checklist (Proposed 2011)

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

CSLF-Project Submission Checklist (2010)

General	
Cost benefit analysis and modeling of CO_2 pipeline and transport systems	
Tanker transport of liquid CO_2	
Specifications for impurities from various processes	
Dispersion modeling and safety analysis for incidental release of large quantities of CO_2	
Safety and mitigation of pipelines through urban areas	

Safety protocols to protect CO_2 pipelines, including response and remediation	
Identify regulations and standards for CO_2 transport	
Integration	
Identify reliable sources of information and data related to the design, cost, and space requirements, operation, and integration of CCS with energy facilities	
Conduct periodic technical reviews of all aspects of recognized large-scale CCS demonstration projects and report on the "lessons learned"	
On a periodic basis, update the Technology Roadmap to include technology gaps identified during the technical assessment of demonstration projects	
Integrate with existing infrastructure	
Cross-Cutting Issues	
Energy price issues would encourage the take-up of CCS	

BACKGROUND DATA

Economics (ZEP, 2011)

Transport cost estimates for CCS demonstration projects, 2.5Mtpa

DISTANCE (KM)	**180**	**500**	**750**	**1500**
Onshore pipe (€/t of CO_2)	5.4	n/a	n/a	n/a
Offshore pipe (€/t of CO_2)	9.3	20.4	28.7	51.7
Ship (€/t of CO_2)	8.2	9.5	10.6	14.5
Liquefaction (for ship transport) (€/t of CO_2)	5.3	5.3	5.3	5.3

Source: ZEP 2011

Transport cost estimates for large-scale networks of 20Mtpa

SPINE DISTANCE (KM)	**180**	**500**	**750**	**1500**
Onshore pipe (€/t of CO_2)	1.5	3.7	5.3	n/a
Offshore pipe (€/t of CO_2)	3.4	6.0	8.2	16.3
Ship (including liquefaction) (€/t of CO_2)	11.1	12.2	13.2	16.1

Source: ZEP 2011

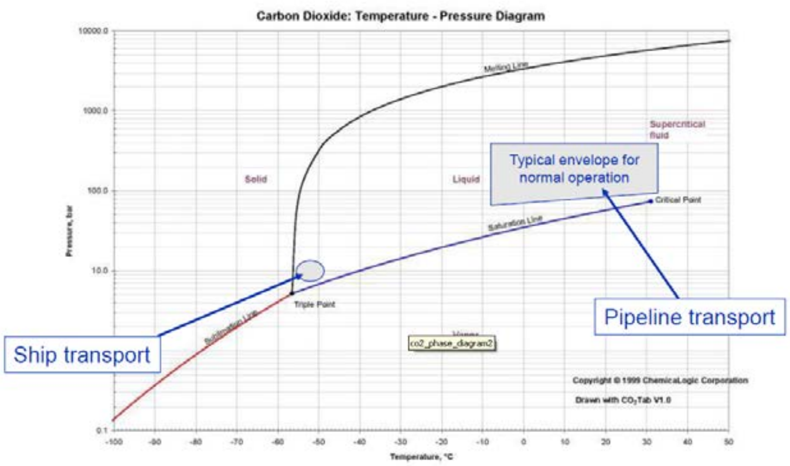

Figure: Phase state of CO2 during transportation. Courtesy of Kaare Helle (DNV), 2011

APPENDIX C.

STORAGE AND MONITORING REPORT

Carbon Sequestration Leadership Forum

Technical Group

Assessing Progress on Technology Issues Affecting CCS

Report from Working group on CO_2 Storage and Monitoring

Stefan Bachu

Alberta Innovates – Technology Futures

and

Lars Ingolf Eide

Research Council of Norway

Summary, Conclusions and Recommendations

Based on the previous Gaps Analysis List, the CSLF Working Group on Storage prepared a modified list of gaps with 34 topics. The 25 CSLF recognized projects with a storage component were then examined and analyzed and a list of gaps vs. project was compiled. In the summer of 2011 a questionnaire with the following questions was sent to the 25 projects:

1. Do you agree to the above list of gaps for your project, or should gaps be added or deleted from the list?
2. Would it be possible for you to let us have
    a. The full objectives of the project, e.g., as stated in the application for funding?
    b. The time schedule of the project with important milestones, original and, if relevant, revised?
    c. A summary of the present status of your projects with emphasis on how far you have progressed towards the objectives and the gaps identified for your project?
    d. Your opinion on any additional work that may be needed when the present project is completed?

Responses were received from 18 projects. As one project had been terminated, the response factor was 75%. Responses varied from a few words for each topic to five pages reports.

In the ensuing analysis we also included projects that did not respond, based on the analysis of available information.

Conclusion/recommendations:

- The survey of the CSLF recognised projects revealed that the following technical issues in the area of CO_2 storage are either poorly addressed or important, and should be focus areas relevant to CCS projects and to the advancement of CO_2 storage:
    - Storage in unconventional media (coals, shales, basalts)
    - Enhanced in-situ mineral trapping and mineralization
    - Storage engineering for pressure and CO_2 plume control
    - Monitoring technologies and leakage detection
    - Effects, risks and remediation of leakage
    - Site management
    - Consolidation of various guidelines and “best practices” manuals
    - Outreach, addressing public concerns, and educating the public and decision makers (political, regulatory, industry)
- The majority of projects are addressing technical and deployment issues, not scientific issues and this should be reflected in the Project Recognition Questionnaire
- The Project Recognition questionnaire should be simplified
- The CSLF Technical Group should refocus its attention and activities in the next 5-10 years to implementation and deployment issues

1. Background

Following meetings of the CSLF Projects Interaction and Review Team (PIRT) in Canberra (1-3 February 2010) and in Pau (15 March 2010), the CSLF Technical Group accepted the recommendation that a new Task Force be formed to assess the progress on closing technology-related gaps that affect the deployment of CCS. The Task Force would complement an ongoing activity of the PIRT to assess the level of CCS readiness of the existing 30 CSLF-recognized projects. However, at the PIRT meeting in Al Khobar on 3 March 011 it was decided to terminate the CCS Technology Readiness Assessment activities and instead undertake only the gap analysis.

The Task Force comprises four Working Groups:

- Capture Technologies Working Group, chaired by George Guthrie, USA
- Transport and Infrastructure Working Group, chaired by Harry Schreurs, Netherlands
- Storage and Monitoring Working Group (hereafter called S&M WG), chaired by Stefan Bachu, Canada
- Integration Working Group, chaired by Kathy Hill, Global CCS Institute

The Working Groups were asked to focus on the progress of each of the technical key elements in the respective field that will affect the deployment of CCS.

As a guide to this effort, the PIRT developed preliminary Gap Analysis Checklists (GAC) of technology-related gaps for each working group during its Canberra meeting. In order to provide an opportunity for project managers to verify the accuracy of the matrix created containing the gaps and the CSLF-recognized projects, the CSLF Secretariat prepared and sent out an individual gap analysis worksheet based on the matrix to each of the 27 active or completed CSLF-recognized projects. Responses were received from 15 projects, and corrections provided in these responses were incorporated into the matrix. The analysis was ready in September 2010 and presented to PIRT in the Warsaw meeting 6 – 8 October 2010. An update version that included responses from a few more projects became available on 18 April 2011, covering 18 projects in total.

Each Working Group was asked to examine the GACs used by the CSLF Secretariat and identify any mistakes, wrong issues, and missing issues relevant to that Working Group, which would allow the Task Force to produce a revised gaps checklist. Each Working Group should then assess how the current CSLF-recognized projects address these gaps, and monitor other projects that address the same gaps.

One application of the GAC would be to help identify new projects that would address any remaining gaps.

2. The Storage and Monitoring (S&M) Checklist

As the S&M WG members worked on the S&M GAC, its granularity increased because Working Group members were adding very detailed subjects and details in their own areas of expertise to the point where it was becoming unmanageable.

It was also noted a certain mismatch between the CSLF Technology Roadmap (TRM) and the GAC in terms of categories – the "Gaps Identification" module of the Roadmap covers only Capture, Transportation, Storage, and Integration, and does not identify Monitoring as a separate category (it is included in Storage). Nor were all items in the TRM addressed by the GAC and vice versa. It was therefore suggested that the Roadmap and the Gap Analysis Checklist should be synchronized at a later stage.

Efforts to balance the granularity of the S&M GAC between the desired and the manageable continued throughout the spring of 2011 and the final version, consisting of 34 items, was approved at the Edmonton meeting of the PIRT and Technical Group on 18 – 20 May 2011. The final GAC as used towards the projects is included as Appendix 1 to this report.

3. Approach

The S&M WG used the list of CSLF recognized projects according to the list as of June 2011 and selected the projects that included storage and/or monitoring. These are listed in Table 1, for a total of 25 projects.

Table 1. CSLF Projects with a storage and/or monitoring component as of June 2011 in alphabetic order

Project Name
Alberta Enhanced Coal-Bed Methane Recovery Project (*project completed*)
CASTOR (*project completed*)
CCS Belchatów Project
CCS Northern Netherlands
CCS Rotterdam
China Coalbed Methane Technology / CO_2 Sequestration Project (*project completed*)
CO_2 Capture Project (Phase 2) (*project completed*)
CO2CRC Otway Project
CO_2 Field Laboratory
CO_2 GeoNet

CO_2 SINK *(project completed)*
CO_2STORE *(project completed)*
Dynamis *(project completed)*
Fort Nelson Carbon Capture and Storage Project
Frio Project *(project completed)*
Geologic CO_2 Storage Assurance at In Salah, Algeria
Gorgon CO_2 Injection Project
Heartland Area Redwater Project
IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project
Lacq CO_2 Capture and Storage Project
Quest CCS Project
Regional Carbon Sequestration Partnerships
Regional Opportunities for CO_2 Capture and Storage in China *(project completed)*
SECARB Early Test at Cranfield Project
Zama Acid Gas EOR, CO_2 Sequestration, and Management Project
ZeroGen Project (Terminated, not included in analysis)

The following questions were asked of all 25 projects along with the GAC:

"The WG on storage has used information on the recognized projects that is available from the CSLF website and other easily available information to identify which projects are addressing the various gaps. From the information at hand we have found that your project "NN" is addressing the following gaps:

XX,YY, ZZ, …. and ...

However, we feel that the information at hand is insufficient to identify the full extent to which your project addresses the gaps and to what extent it will contribute to closing the gap. We will therefore appreciate your feedback on the following:

1. *Do you agree to the above list of gaps for your project or should gaps be added or deleted from the list?*
2. *Would it be possible for you to let us have*
   a. *The full objectives of the project, e.g. as stated in the application for funding?*
   b. *The time schedule of the project with important milestones, original and, if relevant, revised?*
   c. *A summary of the present status of your project with emphasis on how far you have progressed towards the objectives and the gaps identified for your project?*
   d. *Your opinion on any additional work that may be needed when the present project is completed? "*

The questionnaire was sent out in two batches, the first in early July and the second in early August 2011. The survey closed on 9 September 2011. By that time 17 responses had been received. It turned out that one project had been terminated without being completed, thus there were in reality only 24 projects. One response came in late, so the final response was 18 out of 24, or 75%.

Several of the projects in Table 1 are completed as CSLF recognized projects. However, many of them have continued in a new phase and some projects included the activities of the new phase in their responses. To the extent that the continuation addresses one or more gaps, this is included in the results.

For the six projects that did not respond to our survey, the S&M WG used information at hand to find what gaps these projects are addressing. These interpretations are included in the analysis and introduce a small uncertainty in the results.

It should be noted that two of the projects are networks and that their objectives, status and responses may be difficult to interpret in the setting of the gap analysis checklist.

4. Results

The character of the responses varied significantly, from a few words or just a list of gaps that the project addresses, to reports of five pages or more. All responses answered question 1 above by either agreeing or suggesting gaps that should be added to, or deleted from the list.

4.1 Question 1 – projects vs. gaps

The results in terms of "which projects are addressing what gap" were entered into a matrix and the number of projects that are addressing the gaps was summed up. The results are shown in Table 2.

Two general items stand out as not being addressed by any CSLF recognized project:

1. Other storage media than deep saline aquifers
2. Development of guidelines

Table 2. Matrix showing projects that address the different gaps, including non-responses

Gap #	Project																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1				X		X										X				X		X	X				X			X		8
2						X					X									X								X		X		5
3																X																1
4						X	X				X																	X	X			5
5						X					X					X			X	X		X	X							X		8
6																														X	X	2
7						X			X																			X				3
8	X						X				X																	X				4
9																																0
10																																0
11											X									X										X		3
12																																0
13																																0
14			X					X	X		X		X	X					X		X	X	X	X				X				12
15	X						X	X	X										X		X	X										7
16				X				X			X			X					X	X	X	X								X		9
17			X					X	X	X	X		X	X					X	X	X		X	X		X	X	X		X	X	17
18			X					X	X	X	X		X	X					X	X	X	X	X	X		X	X	X		X	X	18
19								X	X	X	X		X	X					X	X	X	X	X	X		X	X	X		X	X	17
20											X								X			X										3
21								X														X										2
22											X								X			X		X							X	5
23			X					X	X		X			X					X			X		X				X				9
24				X						X												X										3
25											X																					1
26																X						X										2
27									X													X	X				X				X	5
28				X	X														X			X					X	X	X		X	8
29						X		X																				X	X		X	5
30			X					X	X		X		X	X										X				X				8
31																																0
32																																0
33																																0
34				X					X	X	X		X	X		X						X	X	X		X	X	X				13
Sum	2	0	5	5	1	6	3	10	10	5	16	0	6	8	0	5	0	0	11	8	6	16	8	8	0	4	7	13	3	10	8	

For the item “storage medium” no activities reported for the following:

- Unmineable coal seams: Improve understanding the effects of coal rank, quality, stress and other properties on storage potential and capacity, as well as injectivity
- Mineral carbonation: Further investigation of the possibilities of enhancing in-situ mineral trapping of CO_2 and impurities in specific types of settings (basaltic and ultramafic rocks, highly saline aquifers, geothermal)
- Mineral carbonation: Enhancement of trapping and reduction of costs to improve viability; assessment of the techno-economic viability of mineral storage of CO_2
- Other geological formations: Improved understanding of the effect of oil and/or gas production from shale (which normally constitute caprocks) on storage integrity (confinement) and capacity

and modest (i.e. $\leq$ 4 projects) activities reported for the following gaps

- Mineral carbonation: Improved knowledge of thermodynamics and kinetics of chemical and microbiological reactions, as well as impacts on fluid flow, injectivity, and geomechanics (1 project)
- EOR: Co-optimization of CO_2 storage and oil production, and conversion from CO_2-EOR to CCS – lessons to be applied to other storage reservoirs (2 projects)
- EGR Validation: of enhanced gas recovery (EGR) (3 projects)
- ECBM: Technical validation of enhanced coalbed methane recovery (ECBM) and proving feasibility on large scale (4 projects)

Within Guidelines Development no activities were reported for the following gaps:

- Development of protocols for assessing well material alteration and forward simulation of well barrier stability over time
- Development of guidelines and procedures for handling saline produced water at onshore as well as offshore sites in the case of engineered sites where water production is used for pressure and CO_2 plume control
- Consolidation of various “best practices” manuals developed or issued by various individual projects or agencies (e.g., Weyburn Project, NETL, IEA-GHG, etc.) into general sets under the auspices of an international agency or organization (e.g., CSLF, GCCSI, etc.).

Other gaps where there are modest ($\leq$ 4 projects) activities are

- Conducting a comprehensive assessment of storage resource data required for estimation of effective storage capacity worldwide, covering separately DSF (deep saline formations), DOGR (depleted oil and gas reservoirs) and UCS (unmineable coal seams).
- Development and application of improved well abandonment practices for CO_2-rich environments
- Extension, development and adaption of a portfolio of remediation measures if leakage occurs
- Deep Saline Formations: Increased knowledge regarding pressure build-up and use of relief wells and water production (“storage engineering”) as a way to

regulate the pressure during CO_2 injection, advantages as well as disadvantages, utilizing data from the petroleum industry
- Improved understanding of, and ability to monitor and assess, the impacts of CO_2 leakage on ecosystems, including marine settings. This formulation is Gap # 25, which is very similar to Gap # 20. Together, four – 4 – projects reported activities here.

The most popular topics addressed by projects are related to monitoring storage complexes and are (all projects are included, not only those that responded):

- Development and application of low cost and sensitive monitoring technologies, including non-intrusive, passive and long term methods, remote sensing and autonomous sampling techniques, onshore and offshore, for both CO_2 and displaced native fluids (e.g., brine) (19 projects)
- Combination and integration of a range of monitoring techniques to improve resolution, temporal as well as spatial, and reduce costs (18 projects)
- Development and application of monitoring techniques and methodologies that allow for detection and quantification of subsurface leakage (18 projects)

followed by Outreach, Modelling activities and Managing the storage site:

- Development of procedures and approaches for communicating the impacts and risks of geological storage to the general public, media and decision makers in the public and private sectors, from the initiation of a CCS project to its closure and liability transfer (14 projects)
- Further development of appropriate coupled models that include multi-phase fluid flow, thermo-mechanical-chemical effects and feedback to predict the fate and effects of the injected CO_2, including faults and other possible leakage pathways (12 projects)
- Improvement and application of risk assessment tools to identify and quantify the likelihood and consequence of CO_2 leaks and inform effective decision making (11 projects).

4.2 Question 2 – Objectives, status and further work

<u>2a – Objectives</u>

The first part of this question was related to the objectives of the project. None of the projects reported changes to the original objectives.

The majority of projects are addressing technical and deployment issues, not scientific issues, whereas the gaps analysis appears skewed towards scientific issues. This raises a question as to the relevance of Project Recognition Questionnaire.

Completed projects reported advances on addressed issues of general, non-site specific nature, e.g. within

- Fluid flow and flow simulations
- Geomechanics
- Monitoring technologies and strategies
- Best Practice Manual

- Issues related to Environmental Impact Statements (EIS)

2b,c – time schedule and status

Of the 25 storage project in the CSLF portfolio nine had been completed and one had been terminated at the time of the survey. Of the remaining eight responses, none reported serious deviations from the original schedule although a few reported that they have applied for extending the project, e.g. to prolong an injection period to allow more time for collection of important and relevant data.

2d – need for additional work

This question was intended for completed or close-to-completed projects. Of the nine completed projects five had a strong site-specific character. However, some of these suggested topics for further work that have a more general character. Summing up responses to these questions it appears that the following general issues should be further addressed in the future:

- Develop and test monitoring technologies for different
    - geological formations
    - depths (improving the upscaling)
- Testing of different, specific CO_2 qualities. The chemical and physical behaviour of these impure CO_2 qualities can be monitored by different well-established monitoring techniques at existing test sites.
- Testing different injection regimes and accelerating storage, e.g., capillary trapping. monitoring and determining the residual gas saturation.
- Performing well-bore leakage tests with monitoring the behaviour of the leaking CO_2 and the influences on well cements, casings and installations.
- Testing different abandonment strategies for the wells. Testing different cementations in combination with smart casing concepts.
- Study fracturing processes / effect of fractures, with respect to CO_2 (directly or indirectly) under controlled conditions
- Further progress in geo-modelling based on results from the projects, e.g. improve predictive reservoir modelling through dual-porosity models and incorporate changes in geochemical and geophysical characteristics.
- Further develop and implement protocols and certification schemes
- Integration of observation well data with other monitoring and field data.
- Near surface monitoring and soil characterization and determining seasonal biogenic CO_2 emissions.

5. Discussion

Large scale storage is taking place today and even larger projects have been approved and are under construction. Thus it is difficult to say that there are gaps in form of technical show-stoppers. One respondent pointed this out:

“ We don’t see any gaps that need closing for our project to proceed. At the end of the day the only real gap that the widespread deployment of CCS suffers from is that today it is terribly expensive and can’t compete with industries that continue to simply vent their emissions. Perhaps reframe your question to one of what areas will the project provide further insights/technical demonstrations of the technology.”

To this one could add two other potential non-technical showstoppers:

- A lack of public acceptance, in particular for onshore storage, as seen in e.g. the Netherlands and Germany
- A lack of international regulations and agreements concerning the storage of CO_2 in marine environments. Although there are positive signs at the national and regional levels, relevant international conventions like OSPAR and London are still not ratified by sufficient number of parties to be legally binding.

A lesson learned during this exercise is the fact that a definition of “gap” may be subjective. Reading through the project descriptions and objectives it appears that many projects have vague or general objectives and that projects interpreted to address the same gaps may have a range of objectives. To determine whether there is a “gap” to close or not, one needs a clear picture of where one is, i.e. state-of-the-art, as well as well where one wants to be, i.e. well defined targets are needed to really identify gaps. CSLF has the former in form of a Technology Roadmap but as group it does not have the latter.

Seen in this context “Technical issues” will be a more relevant concept or a better terminology than “gaps”. We are really looking at activities that will improve tools and reduce uncertainties in CO_2 storage. This in turn may lead to reduced costs and increased confidence in CCS as a climate mitigation option.

This survey has shown that the CSLF recognized projects address most of the identified technical issues but that the majority of the storage projects, as well as the integrated projects with a storage component, are site specific. Therefore, it is recommended that the Project Recognition Questionnaire should be simplified to reflect this fact.

Furthermore, as there appears to be no technical showstoppers and that further work on the technical issues is really a question of improvements rather than removing technical hurdles, it is recommended that the CSLF Technical Group should refocus its attention and activities in the next 5-10 years to implementation and deployment issues.

APPENDIX 1

CSLF List of Gaps
Storage and Monitoring

In this document, the following acronyms are being used:

- **DSF**: deep saline formations;
- **DOGR**: depleted oil and gas reservoirs;
- **EOR, EGR, ECBM**: enhanced oil recovery, enhanced gas recovery and enhanced coalbed methane recovery, respectively.
- **UCS**: unmineable coal seams;
- **OGF**: other geological formations;
- **MC**: mineral carbonation

If no acronym is being used to specify the type of storage unit, it means that the respective gap applies to all categories

According the CSLF Technology Roadmap 2010 the following actions have been identified to close gaps in knowledge and experience for storage and monitoring of CO_2 in geologic formations:

Gap #	**Storage site characterization and capacity assessment, general**	**Project #**	**Total # of projects**
1	Identification of the exploration and data characterization requirements, and lead times required to underpin the development of demonstration projects, for onshore and offshore.		
2	Improving coefficients for storage capacity efficiency in any storage medium based on modelling and field data, and development and adoption of a system of classification of storage resources similar to the ones used in the petroleum and mining industries.		
3	Conducting a comprehensive assessment of storage resource data required for estimation of effective storage capacity worldwide, covering separately DSF, DOGR and UCS.		
4	Production of digitally-based national, regional and worldwide atlases of CO_2 storage capacity, including both quantitative and qualitative assessments of storage potential, and covering separately DSF, DOGR and UCS.		

	Issues specific to the storage medium		
5	**DSF:** Increased understanding and modelling of injecting CO_2 into laterally open aquifers to allow a robust storage capacity estimation under dynamic conditions,		
6	**EOR**: Co-optimization of CO_2 storage and oil production, and conversion from CO_2-EOR to CCS – lessons to be applied to other storage reservoirs		
7	**EGR** Validation of enhanced gas recovery (EGR)		
8	**ECBM**: Technical validation of ECBM and proving feasibility on large scale		
9	**UCS**: Improve understanding the effects of coal rank, quality, stress and other properties on storage potential and capacity, and on injectivity		
10	**MC**: Further investigation of the possibilities of enhancing in-situ mineral trapping of CO_2 and impurities in specific types of settings (basaltic and ultramafic rocks, highly saline aquifers, geothermal reservoirs, shale, etc.) and map these. Build on pioneer studies and prove the concept.		
11	**MC**: Improved knowledge of thermodynamics and kinetics of chemical and microbiological reactions, as well as impacts on fluid flow, injectivity, and geomechanics		
12	**MC**: Enhancement of trapping and reduction of costs to improve viability; assessment of the techno-economic viability of mineral storage of CO_2		
13	**OGF:** Improved understanding of the effect of oil and/or gas production from shale (which normally constitute caprocks) on storage integrity (confinement) and capacity		
	Modelling the storage complex		
14	Further development of appropriate coupled models that include multi-phase fluid flow, thermo-mechanical-chemical effects and feedback to predict the fate and effects of the injected CO_2, including faults and other possible leakage pathways.		
15	Improving tools for automated history matching of models with field observations		
16	Assessing long-term post-injection site security using verified mathematical models of storage		

	Monitoring the storage complex		
17	Development and application of low cost and sensitive monitoring technologies, including non-intrusive, passive and long term methods, remote sensing and autonomous sampling techniques, onshore and offshore, for both CO_2 and displaced native fluids (e.g., brine).		
18	Combination and integration of a range of monitoring techniques to improve resolution, temporal as well as spatial, and reduce costs		
19	Development and application of monitoring techniques and methodologies that allow for detection and quantification of subsurface leakage		
20	Monitoring impacts (if any) on the environment, including sub-aquatic and aquatic		
	Managing the storage site		
21	Development and application of improved well abandonment practices for CO_2-rich environments		
22	Improvement of knowledge of the impact of the quality of CO_2 (that is, purity of CO_2 and effects of other compounds contained in the injection stream) on storage capacity and evolution (behaviour), and interactions with the formation brine, rocks and well cements.		
23	Improvement and application of risk assessment tools to identify and quantify the likelihood and consequence of CO_2 leaks and inform effective decision-making.		
24	Extension, development and adaption of the portfolio of remediation measures if leakage occurs.		
25	Improved understanding of, and ability to monitor and assess, the impacts of CO_2 leakage on ecosystems, including marine settings		
26	**DSF**: Increased knowledge regarding pressure build-up and use of relief wells and water production ("storage engineering") as a way to regulate the pressure during CO_2 injection, advantages as well as disadvantages, utilizing data from the petroleum industry		
27	Development and of application cost-effective engineering solutions to secure long term well bore integrity, including well design, construction, completion, monitoring and remediation		

	Costs and cost evaluation		
28	Investigating the costs associated with storage, including drilling and establishing wells, and monitoring		
	Guidelines development		
29	Improved methodologies and standards to determine practical and matched storage capacity for all types of geological media under current consideration		
30	Development of best practice guidelines (manuals) for storage site selection, operation, monitoring and closure, including risk assessment and response and remediation plans in case of leakage		
31	Development of protocols for assessing well material alteration and forward simulation of well barrier stability over time		
32	Development of guidelines and procedures for handling saline produced water at onshore as well as offshore sites in the case of engineered sites where water production is used for pressure and CO_2 plume control		
33	Consolidation of various “best practices” manuals developed or issued by various individual projects or agencies (e.g., Weyburn Project, NETL, IEA-GHG, etc.) into general sets under the auspices of an international agency or organization (e.g., CSLF, GCCSI, etc.).		
	Outreach and public concern		
34	Development of procedures and approaches for communicating the impacts and risks of geological storage to the general public, media and decision makers in the public and private sectors, from the initiation of a CCS project to its closure and liability transfer		

Additional details used when evaluating projects vs. gap:

<u>Storage site characterization and capacity assessment, general:</u>

Improving coefficients for storage capacity efficiency in any storage medium.

Activities considered for gap closing include*:*

- Development of a robust storage capacity classification system
- Summarizing data needs for storage capacity estimation and site characterization
- Understanding better the effects of variability in rock properties and characteristics on injectivity

- Understanding better the effects of caprock variability and properties on containment and storage capacity
- Proving the concept of storing CO_2 in basalts, organic-rich shale, gas and oil shale, unconventional hydrocarbon reservoirs (heavy oil, tar sands, tight sands)
- Improving data availability
- Understanding the effects of coal rank, quality and other properties on storage potential and capacity (UCS)
- Improved interpretation of cased hole logs for characterization
- Improved functionality and resolution of available logging tools for characterization
- Improved recognition and interpretation of the nature and characteristics of faults and fractures

Comprehensive assessment of storage resource data required for estimation of practical storage capacity world-wide, covering separately DSF, DOGR and UCS.
The compilation must

- Collate and integrate existing national and regional atlases and apply a consistent methodology for storage capacity estimation
- Identify key data gaps for the main emissions-intensive regions in eastern and south Asia, Western Europe and North America
- Identify the exploration operations required to fill the key data gaps in each region
- Estimate the time, resources and expenditure required for the exploration operations

<u>Formation specific issues</u>

DSF*: Increase geological knowledge and process modelling performance that….*
Activities considered for gap closing include*:*

- Further investigates the key reservoir and cap rock characteristics of deep saline formations relevant to storage injectivity, capacity and integrity (geometry, structure, mineralogy, fluid chemistry, petro-physics, hydrodynamics, geomechanics, geothermal gradient, relative-permeability and displacement pressure, etc.)
- Increases the understanding and modelling of injecting CO_2 into open aquifers (laterally open)
- Provides tools for predicting spatial variability in reservoir and cap rock characteristics, with assessment of uncertainties based on data availability and distribution
- Provides a robust storage capacity classification system and informs the legal end of storage licensing procedures

Modelling the storage complex

Further development of appropriate coupled models that include multi-phase fluid flow, thermo-mechanical-chemical effects and feedback to predict the fate and effects of the injected CO_2, including faults and other possible leakage pathways.

Activities considered for gap closing may address one or more components of a coupled system and include:

DSF

- Understanding/determination and documentation of residual gas trapping (relative permeability effects) at laboratory and field scales
- Predicting and modelling spatial reservoir and cap rock characteristics with uncertainties
- Understanding CO_2/water/rock interactions and effects on CO_2 trapping and migration, including effects on porosity and permeability
- Evaluation of basin-wide pressure build-up as a result of CO_2 storage at multiple sites, including assessing sustainability of high injection rates in open and closed systems
- Evaluation of petroleum field development impact on aquifer hydrodynamic regime and storage capacity (this refers to decreased pressure, hence higher storage capacity)
- Impact of the quality of CO_2 (composition of the CO_2 injection stream) on interactions with the aquifer water, rocks and caprock, including impact on storage capacity and containment
- Development of coupled HTMC (hydro-thermo-mechanical-chemical) models for CO_2 injection, migration and leakage for a wide range of in-situ conditions (pressure, temperature, water salinity, rock mineralogy), including the feedback loop
- Improvement of databases of parameters needed for modelling geochemical effects
- Improvement in models and software for basin wide geological, reservoir engineering and hydrodynamic modelling, including the behaviour of the displaced formation fluid

UCS

- UCS: Effects of depth, pressure and stress on coal permeability/injectivity
- UCS: Effects of CO_2-coal interactions, particularly for supercritical CO_2 (swelling, plasticization) and methane displacement

MC

- Thermodynamics and kinetics of chemical and microbiological reactions, and impact on injectivity, geomechanics and fluid flow

Monitoring the storage complex

Development and application of low cost and sensitive CO_2 monitoring technologies, including non-intrusive, passive and long term methods, remote sensing and autonomous sampling techniques.

Technologies and actions to be considered for gap closing may address one or more components of a coupled system and include:

- Seismic and non-seismic geophysical techniques
- Evaluation of permanent or semi-permanent sampling points in an observation well
- Improved wellbore monitoring techniques
- Detection of leakage pathways in confining zones at depth before progressing further
- Estimation of leakage flux rates of anthropogenic and natural systems, including use of improved remote sensing
- Detection and monitoring of CO_2 seeps into subaqueous settings and ground surface
- Use of vegetation changes in hyperspectral surveys changes to identify gas levels in the vadose zone
- Identification and development of monitoring techniques (they should meet the requirements of emission credits and trade system)

Development and application of instruments capable of measuring CO_2 levels close to background and to distinguish between CO_2 from natural processes and that from storage

- Identification of measurement techniques and thresholds for natural and anthropogenic (leaked) CO_2

Managing the storage site

Improved knowledge of the impact of the quality of CO_2 (that is, purity of CO_2 and effects of other compounds) on interactions with the formation brine, rocks and well cements, and storage behaviour

- Understanding of how geochemical buffering limits pH decrease by carbonic acid, thus avoiding the need for expensive materials in new well construction and old wells remediation

Improvement and application of risk assessment tools to identify the likelihood and consequence of CO_2 leaks and inform effective decision making.

Activities considered for gap closing include:

- Detection of initiation of, and sealing of leakage flowpaths in confining zones
- Including induced seismicity and ground movement

- Quantification and modelling of potential subsurface and surface leakage impacts
- Development of risk minimization methods and strategies, including that of leakage
- Assessment of long-term site security post-injection including verified mathematical models of storage

Extension, development and adaption of the portfolio of remediation measures if a leakage occurs. Activities considered for gap closing include*:*

- Detection of initiation of, and sealing of leakage flowpaths in confining zones
- Techniques that can be used to divert CO_2 migration pathways from undesired zones

APPENDIX D.

INTEGRATION REPORT

CCS PROJECT INTEGRATION WORKSHOP – SUMMARY REPORT

Context and Objective of the Workshop

A key function of the Global CCS Institute is to facilitate collaboration and knowledge sharing between CCS projects and participating researchers, governments and industry. This function is achieved primarily through accessing project knowledge through direct support relationships with Members' CCS projects, and from there, disseminating knowledge to Members and the broader CCS community via the Institute's digital knowledge sharing platform.

In addition to direct acquisition of knowledge from individual projects, the Institute organises thematic workshops focused on initial commercial-scale CCS demonstration projects, and in particular, the key challenges facing their development and the lessons learnt that can be derived from them.

One of the key CCS topics identified by Members of the Institute and Carbon Sequestration Leadership Forum (CSLF) Technical Group was that of CCS Project Integration. It is recognised that the current portfolio of proposed industrial-scale projects includes a large proportion of power-related projects which extend the scope of project integration, and for which the project proponents may have or may not have experience or expertise in all of that scope, particularly the storage components. There is a body of CCS project development history and experience that, if documented, would be of value to the newer generation of projects and proponents.

The Institute's achievements to date in the area of CCS project integration include:

- the development of a generic CCS project development framework, including all activities/task to be undertaken in each stage of a CCS project for each CCS component;
- publication, together with American Electric Power, of 'an Integration report' on the Mountaineer project;
- ongoing work with the advanced projects like ROAD (Netherlands), Trailblazer (US), GETICA (Romania) and Pioneer (Canada) to make available the learnings from their FEED/Feasibility processes.

To build on this work and inform the work programs of the Institute and the CSLF Technical Group, a workshop was organised in November 2011 with primary aims to:

- establish a set of priority actions in relation to technical integration, in particular of a capture facility into a host plant; and
- assess support for, and contents of 'A CCS Project Management Handbook' outlining decision gates/criteria across the whole chain and identifying key integration and critical path issues within/between components of the full CO2 chain.

Workshop Format and Presentations

As a part of the Global CCS Institute's focus on assisting CCS projects through knowledge sharing, a one-day workshop was organised in collaboration with the

CSLF to share experiences on CCS project integration, and to identify priority integration topics that need further attention to facilitate CCS project development and deployment.

Attendance at the event was restricted to 50 individuals, and to those directly involved in active commercial-size CCS projects, and/or those that could offer a particular relevant experience. This allowed and encouraged open discussions on a range of technical topics related to CCS project integration. The workshop participants also drilled down into the opportunities and challenges associated with integrating the CCS (value/cost) chain from a commercial and management perspective.
The open panel discussions were chaired by Nick Otter, member of the Institute's Technical Advisory Committee, and fed into by a number of high quality presentations from leading projects with experience on key integration themes.

Project Integration – Integrating a capture facility into a host plant

- Matt Usher, CCS Engineering Manager, American Electric Power (AEP). *Presentation and discussion on the level of integration and key interface points between AEP's Mountaineer generating station and the proposed 235MW application of CO2 capture.*
- Olav Falk-Pedersen, Technology Manager, European CO2 Technology Centre Mongstad (TCM) Project. *Presentation and discussion on performance and availability issues in relation to integrating different capture processes into a natural gas combined heat and power plant.*
- Kevin J. McCauley, Director Strategic Planning, Global Technology, Babcock & Wilcox. *Presentation and discussion on a large-scale validation project of oxy-combustion technology, with a particular focus on integration issues.*

Integrating the CCS Chain – adding transport and storage

- Tony Booer, Marketing and Technique Manager, Schlumberger Carbon Services. *Presentation on the timing of storage site characterisation, taking into account the impacts on overall project schedule and key integration issues within the storage part of the CCS chain.*
- Guy Konings, Market Manager Business Development, Stedin. *Stedin is leading the development of the CO2 collection network in the Rotterdam Port area and presented on integration issues related to CO2 specifications and infrastructure design.*

Integrating the CCS Chain – a commercial and management perspective

- Lewis Gillies, Managing Director – Don Valley Power Project, 2Co Energy. *Presentation and discussion on project integration challenges encountered in 2Co Energy's Don Valley Power Project – primarily from a commercial perspective.*
- Gerbert van der Weijde, Funding Agreement Manager, Maasvlakte CCS Project CV – ROAD. *Presentation and discussion on the project integration requirements from a project management perspective during the FEED phase of a CCS project.*

Highlights of Workshop Discussions and Next Steps

The workshop presenters provided a comprehensive overview of the state of play in relation to CCS project activity in different parts of the world. In addition to sharing experiences, the workshop allowed for open discussions on a range of technical and risk management topics related to CCS project integration, including project element (storage, capture, transport) development schedule staging, heat integration, plant operability, environmental control, CO2 specifications, scale-up challenges, the size of equipment and the physical space required.

CCS Plant Integration

Even though it was agreed amongst most of the participants that the focus of the first large scale CCS demonstration plants in the power sector should be on 'making CCS work at scale' and that real innovation and integration was more something for next of a kind projects. In these 'next of a kind' projects, integration and learning could drive down the costs of CCS, but for now it is importance to strike the right balance between plant operation and integration. Having said that, CCS industry experts acknowledged that more work is needed now in the following areas:

- Integration/regeneration of plant heat (and cooling) in the CO2 capture process;
- integration of environmental control systems (SOx, NOx, and CO2 removal) to maximise
- improvement of options for operational flexibility, while ensuring CCS system reliability;
- impacts of CO2 compositions and impurities for CCS operations (in particular for transportation systems); and
- understanding the scale-up risks of CO2 capture processes.

The speakers also emphasised that one of the keys to successful project integration is to facilitate intensive collaboration and communication between the various entities involved in the project. Indentifying the project team and 'getting them all in the same tent' is key for successful project integration. In the case of oxyfuel technology for example, the industrial gas companies and the power companies have different design philosophies that need to come together in a project.

CCS Project Integration

In the afternoon session, the workshop participants engaged in a dialogue around the commercial opportunities and challenges associated with integrating a CCS project. It was found that in order to establish the commercial structure of a CCS project in a prudent way, it is important to clarify the risks and rewards for each party involved in the project from the start. The discussions on this topic centered around the risk of private sector investment in CCS projects, including project financing, and the role of governments in derisking a project. Furthermore, project economics were compared for projects that utilise CO2 for enhanced oil recovery (EOR) versus ones that are not looking to create an additional revenue stream.

In relation to project integration from a project manager's/project director's perspective, interesting insights were presented on the timing of storage site characterisation and issues associated with balancing transportation systems for CCS. It was mentioned several times that for many individual CCS projects storage is on the critical path and that ideally it is best to first secure a CO2 sink (i.e. storage adequately defined (characterised and permitted)) before commencing on a capture FEED study. In order to manage this scheduling risk, it is recommended to start exploring a portfolio of storage options from the start of the project. The need to invest more heavily on the front end of the project (front end loading or FEL) in order to mitigate risks and cost escalations at a later stage in the project was shared by most workshop participants.

The workshop participants encouraged the Institute and CSLF to continue their work in relation to the development of a generic CCS project management handbook that would highlight key integration issues and associated risks and provide guidance on how they could be addressed. Herein it is important to focus firmly on the more costly aspects of the projects first and to make sure it reads as a practical guideline instead of being prescriptive and academic.

Next Steps

Both the CSLF and the Institute found the workshop discussions a very useful input into their future work programs. The outcomes of the workshop will feed into upcoming events supported/organised by the Institute and CSLF, including an Institute sponsored event in Alberta, Canada on CCS Systems Integration in May 2012 and a CSLF workshop on CO2 capture technologies in Bergen, Norway in June 2012.

Moreover, the Institute will continue with the development of its online CCS project management guide, taking into account the feedback received in the workshop. The Institute will also focus more on the commercial and financial issues related to CCS project development, and has embarked on several studies that look into the nature of business cases for CCS projects, as well as the commercial structure of CCS networks.