CSLF Projects Interaction and Review Team (PIRT)

CCS Technology Gaps Analysis

PIRT FORMATION & OBJECTIVES

Following the Technical group meeting in Melbourne, Australia, in September 2004, a recommendation was put forward for a working group which would assess projects proposed for recognition by the CSLF and review the CSLF project portfolio to identify synergies and gaps that would then act as input for any future revision of the CSLF Technology Road map. This working group was endorsed by the Policy Group at the CSFL meeting in New Delhi in April 2006 and is now known as the Projects Interaction and Review Team (PIRT).

The PIRT has the following tasks:

- Assess projects proposed for recognition by the CSLF in accordance with the project selection criteria approved by the Policy Group. Based on this assessment, make recommendations to the Technical Group on whether a project should be accepted for recognition by the CSLF.
- Review the CSLF project portfolio and identify synergies, complementarities and gaps, providing feedback to the Technical Group and input for further revisions of the CSLF roadmap.
- Identify technology gaps where further RD&D would be required.
- Foster enhanced international collaboration for CSLF projects, both within individual projects (e.g. expanding partnership to entities from other CSLF members) and between different projects addressing similar issues.
- Promote awareness within the CSLF of new developments in CO_2 Capture and Storage by establishing and implementing a framework for periodically reporting to the Technical Group on the progress within CSLF projects and beyond.
- Organize periodic activities to facilitate the fulfilment of the above functions and to give an opportunity to individuals involved in CSLF recognized projects and other relevant individuals invited by the CSLF, to exchange experience and views on issues of common interest and provide feedback to the CSLF.
- Perform other such tasks that may be assigned to it by the CSLF Technical Group.

TECHNICAL GAPS ANALYSIS

In order to complete the task of identifying technology gaps where further research and development would be required, a comprehensive gap assessment began in 2006. The purpose of this was to identify where projects should be encouraged in the CSLF charter, to promote synergies and inform on new developments.

Single well injection test- Alberta Enhanced Coal-bed Methane Recovery Project

The CSLF Technical Group Gap Analysis work was divided into three components: 1) Capture, 2) Storage and 3) Monitoring and Verification. These were initially instigated by completion of three taskforces examining these topics: Task Force to Identify Gaps in $C0_2$ Capture and Transport, Task Force to Identify Gaps in Measurement, Monitoring and Verification in Storage and the Task Force to Review and Identify Standards for $C0_2$ Storage Capacity Measurement. From the results of these taskforces and by scoping out other gaps from within the Core Group and Floating Group within the PIRT, a list of technology barriers to the CCS deployment were identified and are listed in the adjacent table. These technology gaps were assembled at a high level so that more detailed gaps could be addressed underneath key topics.

The 17 projects recognised within the CSLF were then asked to identify if any of their project outcomes would encompass these issues. Many projects were able to respond in time for this poster and the details of their responses are shown in light green. Those in dark green are taken from the projects descriptions on their websites and information sheets An interactive spreadsheet of these responses is available at http://www.cslforum.org/documents/PIRTGapAnalysis.xls

The aim of this poster session is to highlight aspects of projects that currently or plan to fill these gaps, as well as promote discussion of the areas that are not being addressed by CSLF projects.
If any non-CSLF projects wish to consider applying to be recognised as CSLF project, the submission forms are available at http://cslforum.org/documents/ProjectSubmissionForm.doc

			1) Alberta Enhanced Coal-bed Methane Recovery Project	2) CANMET Energy Technology Centre (CETC) R&D Oxyfuel Combustion for CO2	3) CASTOR	4) CO2 Capture Project	5) CO2 GeoNet	6) CO2 Separation from Pressurized Gas Stream	7) CO2 SINK	8) CO2 STORE	9) Feasibility Study of Geological Sequestration of CO2 in Basalt Formations (Deccan Trap) in India	10) China Coalbed Methane Technology/CO2 Sequestration Project	11) ENCAP	12) Frio Project	13) Geologic CO2 Storage Assurance at In Salah, Algeria	14) ITC CO2 Capture with Chemical Solvents	15) Regional Carbon Sequestration Partnerships	16) Regional Opportunities for CO2 Capture and Storage in China	17) IEA GHG Weyburn-Midale CO2 Monitoring & Storage Project
	CAPTURE																		
	Post-Combustion																		
C1		Improved solvent systems			x											x			
C2		Advanced capture systems			x											x			
C3		Power plant concepts to integrate CO2 capture			x	x										x			
C4		CO2 capture pilot plant			x											x			
C5		Fully integrated demonstration plant														x			
	Pre-Combustion																		
C6		Hydrogen-rich turbines		?									x						
C7		Improved air separation processes		?									x						
C8		Improved water-gas shift				x													
C9		Improved H2/CO2 separation				x													
C10		Power plant concepts to integrate CO2 capture		x		x							x						
C11		Polygeneration optimization				x													
C12		Fully integrated demonstration plant																	
	Oxyfuel Combustion																		
C13		Boiler design		?		x							x						
C14		Improved air separation processes		?									x						
C15		Oxy-fuel gas turbines		x									x						
C16		Combustion science		x									x						
C17		Power plant concepts to integrate CO2 capture		x									x						
C18		CO2 capture pilot plant		?									x						
C19		Fully integrated demonstration plant		x									x						
	Industrial applications																		
C20		Capture from non-power industrial processes				x													
	STORAGE																		
	Injection																		
S1		Optimum well spacings and patterns	x			x						x			x				x
S2		Optimum injection parameters	x			x			x			x			x				x
S3		Definition of variable rock facies or rock property types for injectivity			x	x	x								x				x
S4		Sustainability of high injection rates	x			x						x			x				x
S5		Formation water compression / displacement in closed or open system				x									x				x
S6		Reservoir engineering aspects	x						?			x			x				x
	Storage Options				x														
S7		Saline Aquifers – fluids/rock relationships and interactions			x		x		x	?				x	x				
S8		Coal – rock properties	x				x	x				x							
S9		EOR – lessons to be applied to other storage reservoirs					x												x
S10		Depleted oil and gas fields – viability			x										x				
S11		Basalts – proof of concept									x								
S12		Ultra-low permeability rocks (eg organic rich shales, non-conventional reservoirs) – proof of concept										x							
	Trapping																		
S13		Understanding physical or chemical trapping mechanisms			?	x	x		?	x	x				x				x
S14		Migration rate				x			x						x				x
	Hydrodynamics																		
S15		Petroleum field development impact on hydrodynamic regime																	x
	CO_2 properties																		
S16		Behaviour of CO_2 under different regimes of pressure, temperature and fluid mixtures				x			x		?			x					x
	Assessments																		
S17		Storage Capacity assessment methodologies or standards								x								x	x
S18		Country wide or regional assessments of storage potential								x							x	x	x
S19		Innovative methods for assessments of geological storage potential			?												x	x	x
S20		Geological site characterisation, methodologies, techniques and standards			?		x			?									x
S21		Protocols for evaluation of potential sterilisation of existing resources																	x
	Leakage																		
S22		Flux rates of modern and ancient systems																	x
S23		Quantification and modelling of potential subsurface leakage impacts				x													
S24		Existing facilities and materials				x			x										
	Economics																		
S25		Costs of storage			x													x	
	Software																		
S26		Parameters for modelling fluid and rock interactions					x				?			x					
S27		Improvements in software for basin wide geological, reservoir engineering and hydrodynamic model					x							x					
S28		Integration in single software system of geological, reservoir engineering and hydrodynamic aspects	x			x						x							
	Risk																		
S29		Risk assessment models			?	x	x		?		x						x		x
	Public Outreach																		
S30		Procedures and approaches for communicating the impacts of geological storage to the general public			x	x	x		x					x			x		
	MONITORING																		
	Well bore Integrity																		
M1		functionality and resolution of available logging tools				x								x	x				x
M2		Improved interpretation of cased hole logs				x													x
M3		Improved wellbore monitoring techniques				x	x		?					x					x
M4		physical or chemical changes to cement				x	x		?										x
	Identification of faults and fractures																		
M5		use of seismic	x				x		x	x					x				x
M6		non-seismic geophysical techniques	x			x	x								x				
M7		Improved recognition and interpretation of the nature of faults and fractures				x	x								x				x
	Leaks in the subsurface																		
M8		sesimic, resolution							x					?	x				x
M9		seismic, cost reduction					x								x				
M10		evaluation of permanent or semi-permanent sampling points in an observation well												x	x				
	Surface and near-surface leaks																		
M11		detecting CO_2 seeps into subaqueous settings	x				x								x				x
M12		Remote sensing of CO2 flux	x			x	x								x				
M13		use of vegetational changes by hyperspectral surveys changes to identify gas levels in the vadose zone					x								x				
M14		Improved remote sensing to identify souces of CO2				x	x								x				
	Guideline Development																		
M15		determination of effective pre-injection surveys													x				
M16		Improved integration of monitoring techniques	x									x			x				
M17		Identify thresholds of leakage that can be measured													x				

TECHNOLOGY GAPS ANALYSIS RESULTS 1

carbon sequestration leadership forum

MONITORING

	MONITORING	Will your project outcomes encompass any of these issues?	Examples;	1) Alberta Enhanced Coal-bed Methane Recovery Project: Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	1) Alberta: Reference to relevant work ; Publication or website	4) CO_2 Capture Project: Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	4) CO_2 Capture Project: Reference to relevant work ; Publication or website	5) CO_2 GeoNet: Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	5) CO_2 GeoNet: Reference to relevant work ; Publication or website	10) China Coalbed Methane Technology/CO_2 Sequestration Project: Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	10) China: Reference to relevant work ; Publication or website	13) Geologic CO_2 Storage Assurance at In Salah, Algeria: Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	13) In Salah: Reference to relevant work ; Publication or website	17) IEA GHG Weyburn-Midale CO2 Monitoring & Storage Project: Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	17) Weyburn-Midale: Reference to relevant work ; Publication or website
	Well bore Integrity														
M1		Functionality and resolution of available logging tools	Identification of logging tools that have applicability to the monitoring of CO2 storage sites			Integrated "Well Integrity Field Study" includes assessment (well condition), sampling & analysis, model building and history matching, forward simulation and engineering solutions. A completed study " Well-Based In Situ Detection" tested the threshold detectability of CO2 using Schlumbergers RST tool in a pressurized vessel.	Not public yet					In Salah is testing a portfolio of tools		Limited work to this point, final phase will undertake more evaluation	www.ptrc.ca
M2		Improved interpretation of cased hole logs	To determine potential activity outside the casing or identification of problems with cement bonding			See "Well Integrity Field Study" above	Not public yet							as above	
M3		Improved wellbore monitoring techniques	To allow interpretation of activity outside the casing, but in the immediate wellbore area			See "Well Integrity Field Study" above	Not public yet	Variety of subsurface and above surface monitoring techniques being tested in terrestrial and aquatic settings	www.co2geonet.org					as above	
M4		physical or chemical changes to cement				See "Well Integrity Field Study" above	Not public yet	Wellbore materials integrity being assessed	www.co2geonet.org					as above	
	Identification of faults and fractures														
M5		Use of seismic	Regarding identification of open fractures that might be intersected by an expanding CO_2 plume	Geophysical program associated with current multi-well project (CSEMP)		None	NA	Natural analogues where CO2 migration is occuring along fractures being seismically appraised	www.co2geonet.org			In Salah plans to run several seismic options		2D and 3D seismic to identify faults. Reprocessing of older seismic lines to improve interpretation.	
M6		Non-seismic geophysical techniques	Improvements in resolution	Tiltmeters deployed at surface and below surface for current multi-well project (CSEMP).		The "ECBM Monitoring" study models the utility of non-seismic and seismic applications to fault identification in coal systems.	Not public yet	Ground penetrating radar being tested on natural CO2 seepage systems	www.co2geonet.org			In Salah			
M7		Improved recognition and interpretation of the nature of faults and fractures	With seismic, non-seismic or the combination of techniques			See "ECBM" Monitoring" above	Not public yet	Integrated geophysical, petrographic and geochemical techniques being developed	www.co2geonet.org			In Salah		some attempts to use seismic and High Resolution Aeromagnetics to assess nature of faults in the region.	
	Leaks in the subsurface														
M8		Seismic, resolution	Improved vertical resolution			None	NA					In Salah		Estimate of 2,500 tonnes of leakage to an overlying formation as detection limit.	
M9		Seismic, cost reduction	Reduced costs for survey and data interpretation			None	NA	Lower cost seismic techniques being developed	www.co2geonet.org			In Salah			
M10		Evaluation of permanent or semi-permanent sampling points in an observation well	To determine leakage into overlying zones			None	NA					In Salah			
	Surface and near-surface leaks														
M11		Detecting CO_2 seeps into subaqueous settings	Improved methods, particularly dissolved CO_2	Groundwater monitoring to be undertaken as part of CSEMP multi-well pilot		None	NA	Considerable effort being made on natural seeps into lacustrine and marine field labs	www.co2geonet.org			In Salah		Potable water and soil testing of CO2 and other gases.	
M12		Remote sensing of CO2 flux	Develop techniques that can measure low flux increases	Air surveys to be undertaken as part of CSEMP multi-well pilot		The "Direct Detection of CO2 and Methane" study has tested an aerial application over the RMOTC engineered leak site.	Not public yet	Laser techniques being tested on natural CO2 leaks	www.co2geonet.org			In Salah			
M13		Use of vegetational changes by hyperspectral surveys changes to identify gas levels in the vadose zone	Determine optimal times for surveys in different climatic zones, a better understanding of the influence of soil type			None	NA	Marine and terrestrial floras being investigated at natural CO2 seeps and deliberate release labs.	www.co2geonet.org			In Salah			
M14		Improved remote sensing to identify sources of CO2	To allow identification of increased CO_2 fluxes at surface that might be from deeper sources			See "Direct Detection of CO2 and Methane" above	Not public yet	Airborne surveys over natural CO2 seeps	www.co2geonet.org			In Salah			
	Guideline Development														
M15		Determination of effective pre-injection surveys	To provide guidance in the determination of hydrodynamic isolation of the proposed injection zone			None	NA					In Salah			
M16		Improved integration of monitoring techniques	Results of the application of these techniques	Project has allowed for comparative analysis related to reservoir simulators	Improvements in Coalbed Methane and Enhanced Coalbed Methane Reservoir Simulators, W.D. Gunter, D.H.-S. Law and Matt Mavor, Proceedings of the 2005 International Coalbed Methane Symposium, University of Alabama, Tuscaloosa, Alabama, 20p (2005)	None	NA			Project has allowed for comparative analysis related to reservoir simulators	Improvements in Coalbed Methane and Enhanced Coalbed Methane Reservoir Simulators, W.D. Gunter, D.H.-S. Law and Matt Mavor, Proceedings of the 2005 International Coalbed Methane Symposium, University of Alabama, Tuscaloosa, Alabama, 20p (2005)	In Salah			
M17		Identify thresholds of leakage that can be measured	Implications of these on formulating regulation of sites			None	NA	Being assessed at natural CO2 leakage sites				In Salah			

CAPTURE

	CAPTURE	Will your project outcomes encompass any of these issues?	Examples;	3) CASTOR: Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	3) CASTOR: Reference to relevant work ; Publication or website	4) CO_2 Capture Project: Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	4) CO_2 Capture Project: Reference to relevant work ; Publication or website	6) CO_2 Separation from Pressurized Gas Stream: Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	6) CO_2 Separation: Reference to relevant work ; Publication or website	11) ENCAP: Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	11) ENCAP: Reference to relevant work ; Publication or website	14) ITC CO_2 Capture with Chemical Solvents: Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	14) ITC: Reference to relevant work ; Publication or website
	Post-Combustion												
C1		Improved solvent systems	Less energy-intensive, reduced degradation, reduced corrosion, improved operability, new solvent types	Less energy-intensive, reduced degradation, reduced corrosion, improved operability, new solvent types	www.CO2castor.com					N/A		New solvents being developed - individual solvents and mixed solvents. Degradation studies. Corrosion studies, development of corrosion inhibitors. Viscosity. Predictability of properties.	www.co2-research.ca
C2		Advanced capture systems	Membranes, solid sorbents, physical separation techniques, bio-minetic approaches	Membrane contactors						N/A		Some membrane work - membranes as contactors not separators. Work on wettability of membranes.	Volume 45, no. 8 I&EC Research - special report on CO2 Capture. Http://pubs.acs.org/IECR (American Chemical Society for Applied Chemistry and Chemical Engineering)
C3		Power plant concepts to integrate CO2 capture	Process optimization, heat integration, capture readiness	Process optimization, Heat integration		Develop optimized integrated process schemes for power generation with CO2 capture, including Exhaust Gas Recycle and lean combustion. Process studies and lab lean combustion experiments	See: CO2 removal from Power Plant Flue Gas - Cost Efficient Design and Integration Study (Choi et al.) in Results from the CO2 Capture Project -Vol. 1 (ed. D. Thomas) - Elsevier , 2005.			N/A		Limited work on integration at this point although some underway with E.on	
C4		CO2 capture pilot plant	Demonstration and/or testing key components or integrated systems on a scale of MWs to tens of MWs	Pilot plant at Esbjerg Power Station operated by DONG Energy 1ton CO2 / h - Launched in Jan 06						N/A		pilots at 1 tonne per day CO2 and 4 tonees per day CO2 (500,000 scf/day of flue gas from a lignite fired electrical generating station) - one quarter to one third megawatt electricty equivalent	
C5		Fully integrated demonstration plant	Demonstration of long-term operational availability, reliability, technical and environmental performance on a commercial scale using relevant fuels (e.g., coal)							N/A		4 tonne per day plant capable of extended running periods for degradation studies etc. Used primarily for understanding heat rates, process efficiency.	
	Pre-Combustion												
C6		Hydrogen-rich turbines	Develop, validate and demonstrate optimised-low emission hydrogen-rich combustion technology for gas turbines including basic tools and data (CFD codes and kinetics)							Implement new high pressure hydrogen kinetics in CFD codes, validate through experimental testing of reference type combustors. In parallel investigate the hydrogen operational limit of commercial low Nox type combustors, both by numerical simulations and through hign pressure testing. Explore design alterations to achieve near 100% H2 operation.	In general- more info can be found on the ENCAP website at: http://www.encapco2.org/ : For open publications, see below list, they can ususlly be downloaded from sites after "googling" for the title or author:		
C7		Improved air separation processes	High temperature ceramic membranes							Both high temperature oxygen sorbents, ceramic OTM membarnes and ceramic membranes for syn gas production has been investigated. The CAR process has been focused and tested and a specific plan has been made to conduct a more comprehensive test programme and up-scaling.	(see publication list below)		
C8		Improved water-gas shift	Improved catalysts			Develop improved water gas shift technology incorporating hydrogen permeable membranes or selective CO2 adsorbents to push reaction to completion and facilitate capture of CO2. Membrane and adsorbent developments, lab testing, techno/economical evaluations	See: GRACE - Development of supported Palladium Alloy Membranes by Klette et al. In Results from the CO2 Capture Project - Vol. 1 (ed. D. Thomas) - Elsevier, 2005. See: Development of the Sorption Enhanced Water Gas Shift Process - by Allam et al. In Results from the CO2 Capture Project - Vol. 1 (ed. D. Thomas) Elsevier, 2005.			N/A			
C9		Improved H2/CO2 separation	Improved solvents, membranes			Develop improved Pd-membranes for hydrogen separation and solids selectively adsorbing CO2 at water gas-shift conditions. Develop metal membranes for hydrogen separation that may be used in steam reforming conditions. Develop ceramic membranes 100% selective to hydrogen at high temperatures.	See: GRACE - Development of supported Palladium Alloy Membranes by Klette et al. In Results from the CO2 Capture Project - Vol. 1 (ed. D. Thomas) - Elsevier, 2005. See: Development of the Sorption Enhanced Water Gas Shift Process - by Allam et al. In Results from the CO2 Capture Project - Vol. 1 (ed. D. Thomas) Elsevier, 2005. See: Development of a hydrogen membrane for the HMR process concept by Vigeland and Aasen - presented at GHGT-8 - Trondheim, 2006.	Development of CO2 permselective molecular gate membrane for CO2/H2 separation and its test at an elevated pressure	See: S. Duan, T. Kouketsu, S. Kazama, K. Yamada, Development of PAMAM dendrimer composite membranes for CO2 separation, J. Membrane Sci. 283 (2006) 2-6 Also: S. Kazama, T. Kai, T. Kouketsu, S. Duan, H. Oku, F. A. Chowdhury, K. Yamada, Molecular gate functionalized dendrimer membrane for CO2 capture, paper presented at 8th International Conference on Greenhouse Gas Control Technologies (GHGT-8), Trondheim, Norway (2006)	N/A			
C10		Power plant concepts to integrate CO2 capture	Combined shift and separation, hot gas clean-up technology, process optimization, heat integration			Develop integrated process schemes using either combined shift and separation or hydrogen ceramic membranes integrated in the reforming scheme or hydrogen metal reforming membranes. Develop integrated novel schemes to produce power through hydrogen from gaseous fuels using novel hydrogen production and CO2 capture technologies. Lab testing, process optimization, technical/economical evaluations.	See: Development of a hydrogen mixed conducting membrane based CO2 capture process by Vigeland and Aasen, in Results from the CO2 Capture Project, Vol. 1 (ed. D. Thomas), Elsevier, 2005. See: CO2 Capture and hydrogen production from gaseous fuels "CACHET": A new project in EU FP6 (2006-2008) by Forsyth - presented at GHGT-8, Trondheim, 2006.			A complete process for integration in the pre-combustion scheme is researched and developed. This includes the oxygen production and all the steps necessary to realise pre-combustion both for coal and natural gas. Focus is put on both commercial and future applications.			
C11		Polygeneration optimization	Co-production of H2, methanol, ethanol, synthetic fuels, etc. in combination with electricity			Develop integrated process schemes for co-production of power and hydrogen (fuel cell quality) in the same frame described above for power generation.	See: CO2 Capture and hydrogen production from gaseous fuels "CACHET": A new project in EU FP6 (2006-2008) by Forsyth - presented at GHGT-8, Trondheim, 2006.			N/A			
C12		Fully integrated demonstration plant	Demonstration of long-term operational availability, reliability, technical and environmental performance on a commercial scale using relevant fuels (e.g., coal)							No			
	Oxyfuel Combustion												
C13		Boiler design	Optimize, CFB-type units, PC without external recirculation			Develop Chemical Looping Combustion technology for natural or fuel gas boilers through solid carrier development and optimization, lab and bench CFB testing, hydrodynamic studies for optimization of internals.	See: Applicability limits of Fe, Cu and Ni based oxygen carriers in Chemical Looping Combustion by Abad et al., presented at GHGT-8, Trondheim, 2006. See: Chemical Looping Combustion Technology Summary by Hurst and Miracca in Results from the CO2 Capture Project Vol. 1 (ed. D. Thomas) Elsevier, 2005.			Research has been condusted on both CFB and PF type oxy-fuel coal firing for large scale greenfield plants. The systems presumes external recirculation.			
C14		Improved air separation processes	Ceramic membranes, polymeric membranes, others							Both high temperature oxygen sorbents, ceramic OTM membarnes and ceramic membranes for syn gas production has been investigated. The CAR process has been focused and tested and a specific plan has been made to conduct a more comprehensive test programme and up-scaling.			
C15		Oxy-fuel gas turbines	Develop, design and demonstrate components, modules and engines							No - benchmarking of oxy-fuel CC has been condusted with very favourable results.			
C16		Combustion science	Investigation of combustion chemistry, heat transfer and kinetics to improve design, scale-up							Testing in both gaseous oxy-fuel burners and coal fired burners. Mapping of heat release as function of axial distance and emissions, simplified models developed and tested against commercial combustion codes. Oxy-fuel is not well represented in commercial CFD codes.			
C17		Power plant concepts to integrate CO2 capture	Process optimization, heat integration, integration of ASU with process							Conceptually for all kind of variations.			
C18		CO2 capture pilot plant	Demonstration and/or testing key components or integrated systems on a scale of MWs to tens of MWs							Planned to co-operate the phase II of ENCAP with Vattenfalls Schwarze Pumpe oxy-fuel pilot of 30 MWth.			
C19		Fully integrated demonstration plant	Demonstration of long-term operational availability, reliability, technical and environmental performance on a commercial scale using relevant fuels (e.g., coal)							No- although in Phase II of ENCAP valuable data will become available related to oxy-fuel coal PF plants through the data aquisition planned for the Vattenfall pilot in Schwarze Pumpe Plant			
	Industrial applications												
C20		Capture from non-power industrial processes	Steel, cement, refineries, etc.			Study application of CLC combustion to refinery boilers. Study potential and critical issues for CO2 capture from FCC regenerators through oxyfiring.				N/A			

Title	Author(s): Name	Author(s): Affiliation	Conference/Journal
Analysis of Detailed Kinetic Mechanisms for Hydrogen Combustion	T. Myhrvold, J. Ströhle, Ø. Langørgen	Sintef ER	IEA Combustion Meeting(?)
Gas Turbine Cooling Model for Evaluation of Novel Cycles	M. Jonsson[1], O. Bolland[1], D. Bücker[2], M. Rost[3]	[1]NTNU, [2]AP-CH, [3]Siemens	ECOS 2005
Off-Design Evaluation of a Natural Gas Fired Chemical Looping Combustion Combined Cycle with CO_2 capture	R. Naqvi[1], O. Bolland[1], J. Wolf[2]	[1]NTNU, [2]Vattenfall	ECOS 2005
Ceramic Sr-Ce-Co Oxides with high Oxygen Exchange	E. Girdauskaite[1], H. Ullmann[1], V. Vashook[1], M. Bülow[2], U. Guth[1,3]	[1]TU Dresden, [2]BOC, [3]Kurt-Schwabe-Institut für Mess- und Sensor Technik	Solid State Ionics Conference
Flame and Radiation Characteristics of gas-fired O2/CO2 recycle combustion	K. Andersson, F. Jonsson	Chalmers	Fuel
Experimentelle Untersuchung und Bewertung zur Oxyfuel-Verbrennung fossiler Brennstoffe in einem Flugstromreaktor	P. Mönckert, B. Dhungel, H. Wörner, J. Maier, G. Scheffknecht	U Stuttgart	VDI Flammentag
An Integrated Gasification Zero Emission Plant Using Oxygen Produced in a Mixed Conducting Membrane Reactor	E. Lindfeldt[1,2], M. Westermark[2]	[1]AP-CH, [2]Royal Institute of Technology, Sweden	ASME Turboexpo 2006
CO2 Capture by Means of Chemical Looping Combustion	D. Pavone	IFP	FEMLAB Conference
Reduction of a Detailed Reaction Mechanism for Hydrogen Combustion under Gas Turbine Conditions	J. Strøhle, T. Myhrvold	SINTEF ER	Combustion and Flame
CO2 capture using chemical looping combustion for gas turbine application	D. Pavone, M. Rolland, E. Lebas	IFP	GHGT-8, Trondheim
Natural Gas Fired Power Plant Concept with Oxygen Transfer Membrane Reactor and H2 Fired Combined Cyle	G. de Koeijer, M. Gjerset, S. Aasland, H. Kobro, B. Sivertsen, E. Rytter	Statoil	GHGT-8, Trondheim
Oxyfuel Technology for CO2 Capture from Advanced Supercritical Pulverised Fuel Power Plants	Gnanapandithan Sekkappan[1], Peter J Melling[1], Marie Anheden[2], Göran Lindgren[2]	[1]Mitsui Babcock Energy Limited, [2]Vattenfall Utveckling AB,[3]ALSTOM	GHGT-8, Trondheim

TECHNOLOGY GAPS ANALYSIS RESULTS 2

	STORAGE			1) Alberta Enhanced Coal-bed Methane Recovery Project		3) CASTOR	4) CO_2 Capture Project		5) CO_2 GeoNet		10) China Coalbed Methane Technology/CO_2 Sequestration Project		12) Frio Project		13) Geologic CO_2 Storage Assurance at In Salah, Algeria	17) IEA GHG Weyburn-Midale CO2 Monitoring & Storage Project	
	STORAGE	Will your project outcomes encompass any of these issues?	Examples;	Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	Reference to relevant work ; Publication or website	Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	Reference to relevant work ; Publication or website	Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	Reference to relevant work ; Publication or website	Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	Reference to relevant work ; Publication or website	Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	Reference to relevant work ; Publication or website	Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	Project to expand on the specific issues they will address under the relevant gaps and document the levels at which issues are being examined	Reference to relevant work ; Publication or website
	Injection																
S1		Optimum well spacings and patterns	Eg so as to maximise the access to storage capacity in a given reservoir,	Yes – optimum well spacing considered during micro-pilot phase and in multi-well pilot currently being explored with Suncor (CSEMP)			Included in "Certification Framework" Project reservoir simulation module. A generic reservoir model with range of reservoir dimensions / attributes and operating parameters are used to identify injection rates / configurations that would avoid overpressuring or leakage through potential conduits into assets. An additional study "ECBM Operability" examines some of the same issues for coal beds.	Not available yet			Yes – optimum well spacing considered during micro-pilot phase				In Salah has three (horizontal) inection wells whose spacing is fixed. We are studying CO2 movement, such that subsequent projects can optimise well spacing.	Aim to maximise oil production not CO2 storage	www.ptrc.ca
S2		Optimum injection parameters	Eg to avoid geomechanical impacts, or to avoid pressure interference.	Yes – optimum injection parameters a key aspect of current multi-well pilot (CSEMP) operated by Suncor	CO_2 Storage and Enhanced Methane Production: Field Testing a Fenn-Big Valley, Alberta, Canada, with Application, W.D. Gunter, M.J. Mavor and J.R. Robinson, Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies: Volume I, E.S.Rubin, D.W. Keith & C.F. Gilboy (Eds.), Elsevier Ltd., 413-421 (2005)		See "Certification Framework" above				Yes – optimum injection parameters a key aspect of current multi-well pilot being explored for next phase. Micro-pilot and associated modelling highlighted optimal methane recovery rates	ECBM Micro-Pilot Test in the Anthracitic Coal's of the Qinshui Basin, China: Field results and Preliminary Analysis, J. Robinson, B. Kadatz, S. Wong, W.D. Gunter, F. Sangli, and F. Zhiqiang, Proceedings of the Third International Workshop of Prospective Roles of CO_2 Sequestration in Coal Seam, Hokkaido University, Sapporo, Japan, October 2004, 33-44 (2004)	Test sweep efficiency though heterogeneous geologic media	Hovorka, S. D., Doughty, Chistine, Benson, S. M., Freifeld, B. M., Sakurai, Shinichi, Daley, T. M., Kharaka, Y. K., Holtz, M. H., Trautz, R. C., Nance, H. S., Myer, L. R., and Knauss, K. G., 2006, Measuring permanence of CO2 storage in saline formations: the Frio experiment: Environmental Geosciences, v. 13, no. 2, p. 105–121.	Reservoir permeability at In Salah is 10mD. Injection pressure is monitored.	Injection process changes with different patterns. Pressure monitoring to avoid reservoir fracture. Optimise well spacing for rapid recovery.	www.ptrc.ca
S3		Definition of variable rock facies or rock property types for injectivity.	Eg the need to compare the injectivity of thick good reservoir quality (marine deposited sandstone) versus poorer thin bedded (fluvial channel sandstone) reservoirs.				See "Certification Framework" above	Not available yet	Being assessed in geological models workpackage	www.co2geonet.org			This test used very permeable rocks (2 Darcy permeability)		In salah is an excellent illustration of injection into low permeability (10 mD) sandstone, common in North America, China and Europe.	Facies variability built into design of injection processes. Relatively low permeability, shallow marine carbonates. Injectivity has not been an issue.	International Conference on Greenhouse Gas Control Technologies No 7, September 2004 all proceedings volumes.
S4		Sustainability of high injection rates	To match the supply rates and storage volumes at regional or local basin level eg how many separate injection operations could the North Sea sustainably manage in a single reservoir sequence for the time period required?	Yes – especially during micro-pilot phase	Alberta Multiwell Micro-Pilot Testing for CBM Properties, Enhanced Methane Recovery and CO_2 Storage Potential, M.J. Mavor, W.D. Gunter and J.R. Robinson, Proceedings of the SPE Annual Technical Conference and Exhibition held in Houston, Texas, U.S.A., 26–29 September 2004, SPE Paper 90256, 14p (2004)		See "Certification Framework" above	Not available yet			Yes – especially during micro-pilot phase	Enhanced Coalbed Methane – Micro-Pilot Test At South Qinshui, Shanxi, China, Sam Wong, David Law, Xiaohui Deng, John Robinson, Bernice Kadatz, William D. Gunter, Ye Jianping, Feng Sanli and Fan Zhiqiang, Proceedings of the 8th International Conference on Greenhouse Gas Control Technologies (2006)			See above	Numerous injection wells, no well has been stressed with regards to injectivity - the project does not seek to identify injectivity limits.	
S5		Formation water compression / displacement in closed or open system	Eg impacts on potentially compromising groundwater in open system or pressure build-up in closed system.				See "Certification Framework" above	Not available yet							In Salah is injecting into a regional saline formation	This is an EOR process, in other words there is a pressure sink in the form of production wells. The project does not seek to build pressure in the wells beyond maintaining miscibility pressure.	
S6		Reservoir engineering aspects	Eg Near well bore formation damage, hydrate formation, mineral precipitation, effects of impurities in CO_2 stream, etc	Phase IV of project examined different CO2 compositions associated with variety of different industrial applications and attempted to match streams with potential CBM sinks.	Economics of Enhanced Coalbed Methane (ECBM) Production using Different CO_2 Injection Sources: Pure CO_2 versus Coal Combustion Flue Gas versus Acid Gas Streams, Xiaohui Deng, Sam Wong, John Faltinson, W.D. Gunter, Proceedings of the 8th International Conference on Greenhouse Gas Control Technologies (2006)		None	NA			Reservoir engineering aspects considered in advance of micro-pilot phase and currently proceeding in identification of potential reservoirs for a multi-well/commercial project				In Salah will model CO2 movement in the reservoir	The CO2 comes with H2S, but the reservoir is already sour from long use on waterflood. No evidence of formation damage at this point.	
	Storage Options																
S7		Saline Aquifers – fluid/rock relationships and interactions	Aspects that are being focused upon, eg – reservoir / seal continuity, mineralogical considerations, chemical reactions, accessible capacity, stochastic modelling methods, migration pathway prediction, migration pathway volumetric assessment (see trapping mechanisms), seal capacity evaluation at regional scale, injection flow path prediction, reservoir property heterogeneity, etc				Partially addressed by "Certification Framework"	Not available yet	Being assessed	www.co2geonet.org			Test of residual saturation (phase trapping), using pulsed neutron wireline logging, hydrologic methods including introduced tracers, cross well seismic and VSP. Sampling and analysis of pre-injection fluid and rock; monitoring fluid changes during injection. Laboratory fluid-rock interaction for history match. Geochemical modeling.	Hovorka, S. D., Doughty, Chistine, Benson, S. M., Freifeld, B. M., Sakurai, Shinichi, Daley, T. M., Kharaka, Y. K., Holtz, M. H., Trautz, R. C., Nance, H. S., Myer, L. R., and Knauss, K. G., 2006, Measuring permanence of CO2 storage in saline formations: the Frio experiment: Environmental Geosciences, v. 13, no. 2, p. 105–121. Kharaka, Y. K., Cole, D. R., Hovorka, S. D., Gunter, W. D., Knauss, K. G., and Freifeld, B. M., 2006, Gas-water-rock interactions in Frio Format on following CO2 injection: implications for the storage of greenhouse gases in sedimentary basins: Geology, v. 34, no. 7, p. 577–580.	In Salah is injecting into a regional saline formation		
S8		Coal – rock properties	Aspects that are being focused upon, eg - injectivity, swelling, capacity, adsorption, desorption, sealing potential, minable/able coal and change in storage parameters with depth, migration/escape of injected CO_2 or released methane, etc	Analysis of rock properties is fundamental to this project. Properties tested during micro-pilot and again during current multi-well pilot	Secondary Porosity and Permeability of Coal vs. Gas Composition and Pressure, M.J. Mavor and W.D. Gunter, SPE Reservoir Evaluation and Engineering, 114-125 (April, 2006)		None	NA	Being assessed	www.co2geonet.org	Analysis of rock properties is fundamental to this project. Properties tested during micro-pilot and again during current multi-well pilot	Secondary Porosity and Permeability of Coal vs. Gas Composition and Pressure, M.J. Mavor and W.D.Gunter, SPE Reservoir Evaluation and Engineering, 114-125 (April, 2006)					
S9		EOR – lessons to be applied to other storage reservoirs	Aspects that are being focused upon, eg CO_2 sweep characterisation, injection flow path prediction, storage effectiveness, etc			Feasibility study of EOR / long term storage for Casablanca oilfield (Repsol, Spain)	None	NA	Being assessed	www.co2geonet.org						The project deals with sweep efficiency and transport of CO2 within the reservoir. Simulation and monitoring used to understand flow paths. Geochemical monitoring to identify geochemical interactions in the reservoir. Seismic able to "see" CO2 in the reservoir. Laboratory evaluation of mobility control techniques. Storage integrity - including simulation of wellbore failure, cement properties, caprock integrity.	
S10		Depleted oil and gas fields – viability	Aspects that are being focused upon, eg timing of availability, implication for trap and seal integrity due to production operations, ongoing use of existing materials and facilities (remediation / abandonment), etc			Performance assessment for 2 depleted gasfields (K12b, Atzbach) and 1 depleted oilfield (Casablanca)	None	NA							In Salah is injecting into a depleting gas field		
S11		Basalts - proof of concept	Aspects that are being focused upon eg – demonstration of injectivity, capacity methodology, sub-basalt sedimentary basins, intra-basalt sediments, sealing properties, chemical reactions, etc				None	NA									
S12		Ultra-low permeability rocks (eg organic rich shales, non-conventional reservoirs) – proof of concept	Aspects that are being focused upon eg – injectivity, geomechanical impacts, adsorption properties, etc				None	NA			Yes – CBM formations typically have low-permeability						
	Trapping																
S13		Understanding physical or chemical trapping mechanisms	Eg time frames (10s to 100s years) and effectiveness of the variety of trapping processes that occur in reservoirs, eg structural, buoyancy, residual gas, adsorption, mineralisation, dissolution				Partially addressed by "Certification Framework"	Not available yet	Considerable effort being made	www.co2geonet.org					In Salah	Extensive deterministic and probabilistic simulation of long-term storage (to total dissolution of CO2). Thousands of years. Limited evaluation of mineralisation - Limited reactive mineral content of reservoir may mean that not all CO2 could be mineralised.	
S14		Migration rate	Eg Quantification of migration rate of CO_2 and its impact on various trapping mechanisms (hydrodynamic, dissolution)				Partially addressed by "Certification Framework"	Not available yet							In Salah	Project not really designed for this, although breakthrough was recorded as well as timing of chemical changes to water.	
	Hydrodynamics																
S15		Petroleum field development impact on hydrodynamic regime	Eg Pressure draw down in depleting(ed) oil and gas fields – how it affects migration pathways of injected CO_2 within the basin.				None	NA								Not really relevant to this work. Extensive work on hydrodynamic regime of the basin. Some concerns with possible loss of CO2 as a solvent to an underlying aquifer, but this is sealed zone so no issues with CO2 migration out of the area for containment.	
	CO_2 properties																
S16		Behaviour of CO_2 under different regimes of pressure, temperature and fluid mixtures	Eg dissolution trapping processes, multi phase fluid flow, etc				Partially addressed by "Certification Framework"	Not available yet								EOR project so aim is to maintain the CO2 at supercritical for miscible flood.	
	Assessment																
S17		Storage Capacity assessment methodologies or standards	Improved methods to accurately assess potential storage capacity at local or regional level				None	NA								Provides an assessment of the amount of CO2 that could be stored in the reservoir should maximisation of CO2 storage be the aim.	
S18		Country wide or regional assessments of storage potential	Eg need to have regions "storage ready" prior to power plant construction				None	NA								Not undertaken in this study, but finding could be used to extrapolate to many reservoirs in the region.	
S19		Innovative methods for assessments of geological storage potential	Eg improved methods / standards to assess areas where there is a paucity of direct data, both in shallow and deeper sections or where petroleum potential is poor, etc				Partially addressed by "Certification Framework" site assessment module.	Not public yet								Provides a good database that could be used in assessment of other areas where data is limited. This has not yet been undertaken.	
S20		Geological site characterisation, methodologies, techniques and standards	Eg what approaches and standards will be acceptable to adequately characterise a site, best practice manuals, or derive rock parameters where there are no physical samples – eg geophysical remote sensing techniques to predict reservoir quality				None	NA	Considerable effort being made	www.co2geonet.org			Application of standard reservoir and hydrologic approaches to produce rigorous baseline characterization	Hovorka, S. D., Knox, P. R., Holtz, M. H., Yeh, J. S., Fouad, Khaled, and Sakurai, Shinichi, 2003, Tapping the potential for large volume sequestration—update on the Frio brine pilot project (abs.): in Briefing book: Second Annual Conference on Carbon Sequestration: developing & validating the technology base to reduce carbon intensity, Alexandria, Virginia, May 5-8, unpaginated.		Geological characterisation is excellent, provides guidance for other studies. Use of datasets could be undertaken to help provide information on similar geological settings.	
S21		Protocols for evaluation of potential sterilisation of existing resources	Eg impact on groundwater, petroleum production or coal mining				See "Certification Framework" Risk Assessment protocol	Not available yet								Nothing undertaken.	
	Leakage																
S22		Flux rates of modern and ancient systems	Eg analogue studies both as seepage at surface and leakage within the subsurface migration system				None	NA	Considerable effort being made	www.co2geonet.org							
S23		Quantification and modelling of potential subsurface leakage impacts	Eg what leakage is acceptable (in both volume and time) out of the primary storage formation relative to timing and volume of potential final escape to the atmosphere			Leakage scenarios modelling for the 4 sites	See "Certification Framework" Risk Assessment protocol	Not available yet					Pioneer above zone monitoring techniques- test for tracer and geochemical change in next sandstone above injection zone.	Hovorka, S. D., Sakurai, Shinichi, Kharaka, Y. K., Nance, H. S., Doughty, Christine, Benson, S. M., Freifeld, B. M., Trautz, R. C., Phelps, Tommy, and Daley, T. M., 2006, Monitoring CO2 storage in brine formations: lessons learned from the Frio field test one year post injection, in Proceedings of the 2006 UIC Conference of the Groundwater Protection Council, Abstract 19.		Attempt to understand possible migration along old wellbores. Partial quantification.	
S24		Existing facilities and materials	Eg Risks of leakage from abandoned wells caused by material and cement degradation.			Risk of leakage through wellbores and caprocks	Integrated "Well Integrity Field Study" includes assessment (well condition), sampling & analysis, model building and history matching, forward simulation and engineering solutions.	Not available yet								Note above.	
	Economics																
S25		Costs of storage	Eg impacts on costs of source sink matching, site development, reservoir parameters, economies of scale, "smart" well design, etc				None	NA								Some economic analysis on EOR potential.	
	Software																
S26		Parameters for modelling fluid and rock interactions	Eg improved algorithms specifically for CO_2 behaviour either physically or chemically, or long time periods required				None	NA	Considerable effort being made	www.co2geonet.org			TOUGH2 CO2 code validation	Modeling supercritical CO2 in heterogeneous porous media, C. Doughty and K Pruess, http://www.osti.gov/energycitations/servlets/purl/835346-48lupa/native/835346.pdf		Use of standard software.	
S27		Improvements in software for basin wide geological, reservoir engineering and hydrodynamic model	Eg most software is only fully functional at local field level, not basin scale – heterogeneity issues (see Sustainability of the high injection rates)				None	NA	Heterogeneity issues being addressed	www.co2geonet.org						Use of standard software.	
S28		Integration in single software system of geological, reservoir engineering and hydrodynamic aspects	Eg – allow for single predictive software system rather than "bolting" together different systems and results	Project has allowed for comparative analysis related to reservoir simulators	Improvements in Coalbed Methane and Enhanced Coalbed Methane Reservoir Simulators, W.D. Gunter, D.H.-S. Law and Matt Mavor, Proceedings of the 2005 International Coalbed Methane Symposium, University of Alabama, Tuscaloosa, Alabama, 20p (2005)		The aim of the "Certification Framework" is to streamline and place on a single platform site assessment, reservoir simulation and risk assessment. An additional project "Coupled Geochemical-Geomechanical Simulation" is also relevant.	Not available yet			Project has allowed for comparative analysis related to reservoir simulators	Improvements in Coalbed Methane and Enhanced Coalbed Methane Reservoir Simulators, W.D. Gunter, D.H.-S. Law and Matt Mavor, Proceedings of the 2005 International Coalbed Methane Symposium, University of Alabama, Tuscaloosa, Alabama, 20p (2005)				Standard software.	
	Risk																
S29		Risk assessment models	Eg Development, verification and quantification, and grow with experience base				Screening RA is included in the "Certification Framework"	Not available yet	Considerable effort being made	www.co2geonet.org						Extensive RA work, including the development of a new probabilistic software CQUESTRA. Experience can be built on and datasets used in other RA work.	
	Public Outreach																
S30		Procedures and approaches for communicating the impacts of geological storage to the general public	Eg Education programs				The CCP2 SMV Storage Program coordinates with the CCP2 Policies & Incentives and Communications Programs to communicate storage technical assurance issues to focus groups (NGOs) who in turn communicate with the Public.	Not available yet	Considerable effort being made	www.co2geonet.org			Public outreach though many media, including one-to-one. Survey of public opinion.	Public perception of carbon dioxide capture and storage in Texas, Rebekah Lee, Dissertation for final Honours: School of geography, Oxford University, UK 2007	In Salah is producing outreach materials	Very little.	