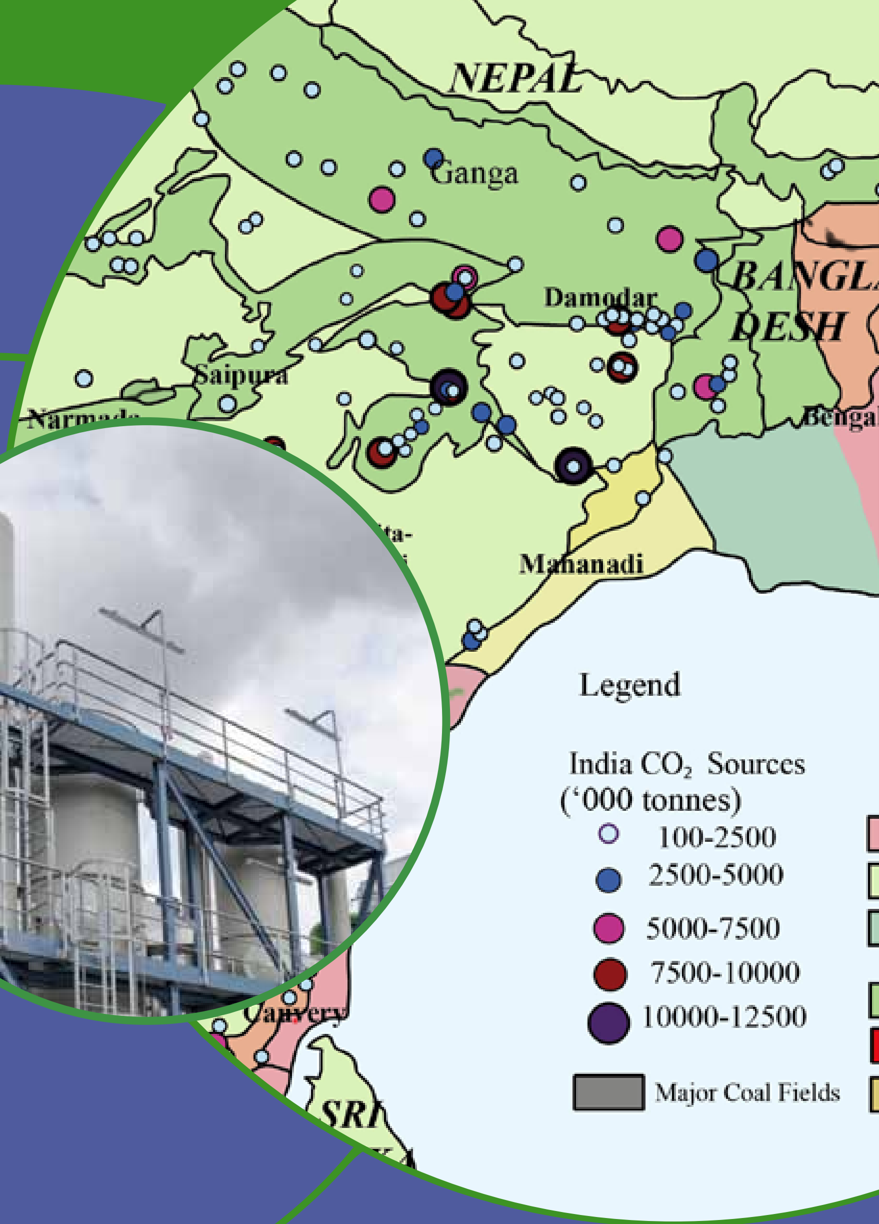
Evaluating technology options to mitigate greenhouse gas emissions



what have we learned?

IEA GREENHOUSE GAS R&D PROGRAMME

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. The IEA fosters co-operation amongst its 28 member countries and the European Commission, and with other countries, in order to increase energy security by improved efficiency of energy use, development of alternative energy sources and research, development and demonstration on matters of energy supply and use. This is achieved through a series of collaborative activities, organised under more than 40 Implementing Agreements. These agreements cover more than 200 individual items of research, development and demonstration. The IEA Greenhouse Gas R&D Programme is one of these Implementing Agreements.

Disclaimer

Date Published: August 2010, Review compiled and designed by Toby Aiken.

Front & back cover images all from the IEAGHG Study Reports

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Introduction: Basis for the What Have We Learned Exercise

Introduction

This report summarises key learning points on CO_2 Capture from Phase 5 of the IEA Greenhouse Gas R&D Programme (IEAGHG). Phase 5 of IEAGHG commenced in January 2005, and a list of the reports published can be found in Appendix 1 at the back of this report.

IEAGHG activities have resulted in recommendations for research and activities on different areas of interest. These recommendations include areas such as: integrated gasification combined cycle (IGCC), small & medium stationary sources of CO_2, the preparation of guidelines for capture ready, industries where biomass is used as fuel, a full life cycle emissions analysis, environmental impacts of solvent scrubbing, permitting guidelines for capture plants, safety and incident database for the CCS industry. In addition, after evaluating the IEAGHG studies, different areas were defined as missing or not covered through IEAGHG studies in the period 2005-2009.

These areas of interest include:

- A guideline for capture processes techno-economic benchmarking, comparison and evaluation.
- CO_2 capture risk assessment.
- CO_2 capture scale-up challenges and strategy.
- Overviews of the CO_2 capture global R&D and commercial activities.
- A detailed technical study on the IGGC development and new technologies.
- More detailed technical and engineering studies (process and heat integration, process design and development).

IEAGHG proposes to continue to focus on these knowledge gaps, through selected studies, the continued activities of the international research networks and collaborative research with other organisations.

IEAGHG study reports represent a considerable body of knowledge on CCS, and recent (post 2004) studies have provided reports that serve as reference documents for key aspects of CO_2 capture and CCS including post-combustion, pre-combustion, oxyfuel combustion, capture economics, environmental impact, capture ready, retrofit of CO_2 capture, biomass fired power plants, CO_2 capture from medium scale combustion installations, safety of CCS, CCS permitting and financing issues, and CCS in CDM.

Techno-Economic Factors

The increase in electricity generation costs, efficiency losses and CO_2 avoidance costs are generally similar for the three major capture technology options (post- pre- and oxyfuel), and although the Oxyfuel option requires further development in key areas, none of these are considered as show stoppers.

For post combustion capture it is noted that solvent scrubbing is considered the state of the art and the solid adsorbents and membrane based processes are considered to be 2nd or even 3rd generation technologies. When comparing the physical absorption processes for pre-combustion capture, the Rectisol process results in lower operating costs, but corresponding capital costs are higher than the alternative Selexol process. However, there is a need to continue with efforts to improve the solvent scrubbing elements of capture technologies, as this has the potential to impact greatly on the costs of capture technologies; one of the key barriers to overcome for widescale deployment. The ever-changing economic climate means that the economic evaluation and estimates of costs remain uncertain, and these elements require specific caution when making comparative assessments.

Retrofit options for post-combustion capture suggest lower capture costs and a smaller reduction in efficiency than pre-combustion, as the additional infrastructure is simpler to retrofit, and requires less process adjustments.

It was clear from analysis of the studies completed, that the optimum economic situation for demonstration plants should be the adoption of greater investment in optimum capture plants, rather than a predominant focus on the 'near zero emissions' scenario. The additional costs incurred in reducing emissions to as great an extent as possible could mean that, economically, the scenario becomes less attractive commercially, and feasibility is compromised. Oxyfuel technology offers the best suited process to high capture ratios, followed by post-combustion processes. These 2 options also offer more competitive scenarios compared with IGCC for lower rank coals.

Capture of CO_2 emissions is classed as having a net environmental benefit due to the avoidance of CO_2 emissions, however there are valid concerns that require further investigation regarding the solvent losses and other waste products from the capture plants, and this represents an area for further work and research.

From the evaluation of the use of biomass as a fuel in the power sector, it is clear that a higher loss in net power plant efficiency, larger increase in the capital costs and cost of electricity can be observed for standalone biomass power plants compared to biomass co-fired power plants.

Capture from medium scale installations will be affected to a greater degree by the carbon price and the possibility of collection networks and storage site availability. (possible collection network diagram) Capture from other sources, such as the cement industry will predominantly feature Oxyfuel and post-combustion processes, with oxyfuel offering the lower cost, and post-combustion offering the easier retrofit option. (image from cement report) It is anticipated that fuel cell combined heat and power (CHP) systems will only make a small contribution to emission reduction targets, mainly in the domestic housing energy market.

Health & Safety

Although there are hazards recognised as being associated with CCS operations, studies suggest that there are no fundamental safety issues that are beyond manageable constraints and these should not be seen as show stoppers.

The capture and transport aspects of the CCS chain are seen by some to be inadequately covered by existing regulations. Although the storage side of the chain requires significant adaptation and development of existing permit award processes, the regulatory implements are in place. Developments are therefore likely to be directly linked to regulatory reform and development.

Wood as Source of Biomass

The biomass referred to throughout the Biomass Fired Power Plants study was clean, virgin wood and wood chips

Conclusions

Having completed a thorough analysis on the investment decision in the power sector, it appears that the abatement of greenhouse gas emissions is counted as a factor in determining the choice of power generation method when designing new plants. In order to progress to large scale demonstration plants, governments are required to provide financial support to the early projects, and determine robust policies to provide certainty to investors. It is thought that the inclusion of CCS in the CDM may not significantly affect the global carbon market in the near or medium term future.

Schwarze Pumpe, Germany

The Oxyfuel Demonstration plant of Vattenfall hopes to demonstrate large-scale capture using Oxyfuel Combustion technology

What Have We Learned from IEAGHG CO_2 Storage Technical Studies?

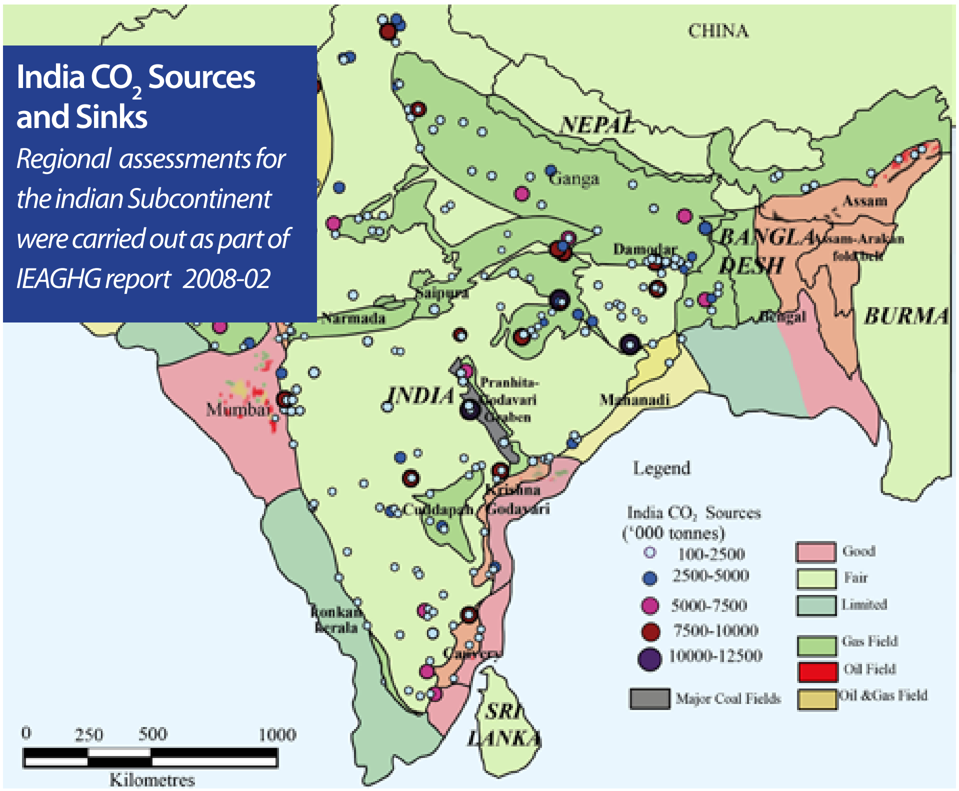
This section summarises key learning points on CO_2 geological storage from Phase 5 of IEAGHG, which commenced in 2005 and effectively coincided with the publication of the IPCC Special Report on Carbon Dioxide Capture and Storage (IPCC SRCCS). IEAGHG storage activities revolve mainly around contracted studies and organisation of the international research networks.

IEAGHG studies are chosen by programme members and sponsors from a wide list of proposals, ensuring those selected are focussed on topical technical issues. Study reports issued from 2005 onwards have contributed significant knowledge to major storage topics, including: regional capacity estimation and associated methodologies; site selection and characterisation; storage capacity in depleted gas and oil fields; storage development issues for deep saline formations (DSF); economics; risk assessment topics including environmental impacts, well integrity and remediation of seepage; and storage economics

IEAGHG has operated 3 international research networks on CO_2 geological storage since 2004/5, covering monitoring, risk assessment and wellbore integrity. A fourth network addressing subsurface modelling was launched following a successful workshop held on this subject in February 2009; and a fifth network on social research was launched in December 2009. Network meetings are held on an annual basis and serve as a forum for the sharing of expert knowledge and ideas; meeting agendas are designed to maximise the time available for discussions. With the launch of a modelling and social research networks in 2009, the IEAGHG vision is for the monitoring, wellbore integrity, modelling and social research networks discussions and outcomes to inform the risk assessment network, which should consider wider risk management issues and act as a forum for contact with regulators.

Storage Capacity

IEAGHG studies have assessed regional storage capacity for North America, Europe and the Indian Subcontinent; the latter can be regarded as 'novel' work in highlighting the significant potential for CCS in that region. Two further studies published in 2009 looked at the global potential for storing CO_2 in depleted gas fields and in association with CO2EOR, respectively.The study on gas field storage provided a fresh perspective on global CO_2 storage potential by placing capacity estimates generated in the context of the CSLF resource pyramid; the study demonstrated how progressive application of various technical and economic factors serves to reduce estimated storage capacities to more realistic levels. The study estimated 160Gt of matched storage capacity in depleted gas fields that could be available globally by 2050, representing a more meaningful assessment than the previously reported 797Gt by an IEAGHG study in 2000, and similar estimates quoted elsewhere.



India CO_2 Sources and Sinks

Regional assessments for the indian Subcontinent were carried out as part of IEAGHG report 2008-02

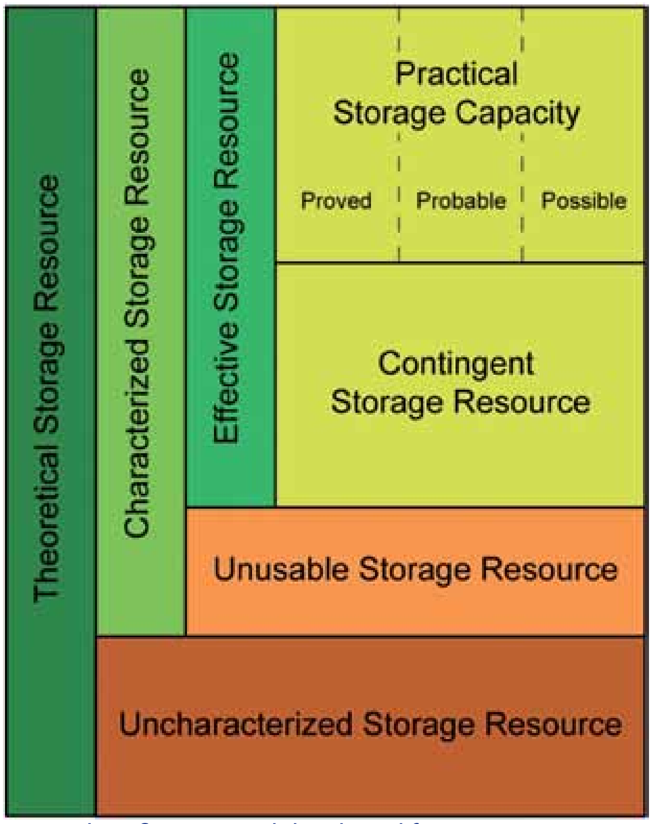


Figure 1: Classification grid developed for storage capacity calculations as part of IEAGHG report 2009-13

The second study utilised the USGS World Petroleum Assessment and additional information on US basins; screening criteria based on US CO2EOR experiences were used to convert original oil in place (OOIP) in the top 54 hydrocarbon basins around the world, into technically recoverable OOIP using CO2EOR (Table 1). The study estimated global CO_2 storage capacity associated with CO2EOR as 140Gt, of which over 70% is within the world's 'top ten' basins. Source-sink matching considerations could significantly reduce this potential; for example by applying an 800km limiting distance between current industrial CO_2 sources and major fields, the CO_2 storage capacity associated with CO2EOR could be reduced to 65Gt. However, new anthropogenic sources are likely to be established in coming decades, including in the Middle East.

Whilst storage in depleted hydrocarbon fields provide significant advantages for CO_2 geological storage in terms of known capacity, injectivity and containment, storage in DSF is widely held to offer the largest potential capacity for storage, as highlighted in many storage mapping publications including the US Department of Energy/ National Energy Technology Laboratory (US DOE/NETL) Carbon Sequestration Atlas and the EU Geocapacity Project. In 2008, IEAGHG in conjunction with US DOE/ NETL, commissioned a study to determine storage capacity coefficients (or efficiency factors) for DSF, as required by both the US DOE and Carbon Sequestration Leadership Forum (CSLF) capacity estimation methodologies (figure 1). The results of the study were published in a 2009 IEAGHG report and are being used to adjust storage capacities in the 2010 update of the US atlas; in brief, derived mean capacity coefficients range between 2.0% and 3.3% of storage formation theoretical pore space, depending on lithology. The modelling work used to derive the coefficients assumed open system conditions, i.e. regional lateral hydraulic connectivity, allowing migration of displaced formation brine and dissipation of pressure away from the storage site.

US Basin / Area	ARI Data			Data from Regression			
	Technically Recoverable EOR (MMBO)	CO_2 Stored (Gt)	CO_2/Oil Ratio	Technically Recoverable EOR (MMBO)	CO_2 Stored (Bcf)	CO_2 / Oil Ration	Difference
East / Central Texas	9,392	2.42	0.26	8,969	2.33	0.26	1.1%
Permian	13,428	4.10	0.31	13,583	4.08	0.30	-1.8%
Mid-Continent	6,359	1.61	0.25	5,777	1.51	0.26	3.6%
North Slope	11,373	3.08	0.27	10,269	3.07	0.30	10.2%
Gulf Coast	4,131	1.32	0.32	4,316	1.37	0.32	-0.8%
San Joaquin	2,164	0.54	0.25	1,746	0.50	0.28	14.8%
Rockies	2,625	0.74	0.28	2,811	0.80	0.28	0.1%
Los Angeles	1,096	0.29	0.27	1,271	0.34	0.27	1.0%
Coastal California	1,179	0.34	0.29	847	0.23	0.27	-6.5%
Williston	1,827	0.49	0.27	1,651	0.52	0.31	16.6%
Cook Inlet	670	0.21	0.32	656	0.20	0.30	-5.4%
Total	54,243	15.1	0.28	51,897	14.9	0.29	3.1%

Table 1: Comparrison of Estimates of CO_2 Storage Potential from the Application of CO2EOR in U.S. Basins

Site Selection and Characterisation

IEAGHG issued a report in 2009 on site selection and characterisation. Site characterisation is a continuous and iterative process that starts usually with existing data, particularly at the basin and/or regional scale, and proceeds with the acquisition of new data and information during all the stages of a CCS project relating to the site, namely: selection, evaluation, permitting, design and construction, operation, closure and post-closure. However, the major effort and expenditure of resources occur in the early stages of site selection and permitting. The initial characterisation will be subsequently updated with data and information produced by new well drilling and from monitoring programmes.

Sites should be characterised in terms of geology, rock properties, hydrogeology and geothermics, fault and fracture characteristics - if present, in-situ conditions, composition and phase behaviour of the native fluids and the injected CO_2 stream, reservoir history in the case of hydrocarbon reservoirs, history of wells and their condition, and land features.

Performance assessment is an integral part of site characterisation and is based on numerical modelling of multi-phase, non-isothermal, reactive flow that takes into account hydrodynamic, thermal, geochemical, geomechanical and geophysical effects of CO_2 injection and storage under various scenarios, taking into account also the uncertainties introduced by data availability, distributions, resolution, accuracy and quality, and also the necessary assumptions, simplifications and resolution of the modelling process. The IEAGHG modelling network continues to focus on these various topics.

IEAGHG has commissioned a study in 2010 which will look at the technical and financial resources required to select and characterise storage sites to allow commercial implementation of CCS on a global scale, for example as highlighted by the IEA CCS Roadmap published in 2009.

Development Issues for Deep Saline Formations

A 2008 IEAGHG study report provided a comprehensive review of development issues for DSF (Table 3). The report concluded that storage of CO_2 in deep saline formations can be regarded as a proven technological option. However, as highlighted in several presentations at the GHGT-9 conference in Washington DC in November 2008, further understanding of the related issues of brine displacement and pressurisation is required before widespread utilisation of these formations for storage is possible.

An IEAGHG study published in 2010 on injection strategies for DSF storage, concluded that pressure build-up due to injection in DSF is potentially the most significant limiting factor for large-scale geological storage. (table or image from injection report) Due to this, strategies for pressure management as an element of injection strategies will need substantial consideration for future CCS projects. Experience gained from further large scale injection schemes will be crucial in this regard. The report described how the use of abstraction wells, as proposed for example in the Australian Gorgon storage project, could be used to manage pressures in storage formations and enhance dissolution of CO_2 in brines.

A further IEAGHG study, looking specifically at brine displacement and pressurisation will be published in 2010.

Risk Assessment

Studies have highlighted the need for further research on environmental impact assessment in the context of CO_2 geological storage. Although there is an existing knowledge base on the effects of CO_2 on ecosystems, a number of gaps in knowledge have been highlighted. Regulatory and industry attitudes to risk assessment for CO_2 geological storage were examined in a 2007 questionnaire-based study. The study found no major discrepancies between attitudes of the two groups to risk assessment, which will provide an essential framework for the regulation of storage. Network discussions have recognised performance and impact assessments as twin components of risk assessment, which forms part of a wider risk management process that incorporates monitoring and mitigation. These discussions have also highlighted the fact that current understanding of performance assessment and environmental impacts renders quantitative risk assessment as problematic.

Integrity and remediation of CO_2 injection wells are not considered to be major technical obstacles to storage, but potential leakage from abandoned wells could be far more problematic for some storage scenarios. Research continues to focus on the effects of CO_2 on cements and other wellbore materials, however there is an increasing recognition that characterisation of pre-existing fractures and material interfaces in wells is required to understand leakage potential.

A 2009 IEAGHG report on wellbore abandonment demonstrated that there is much experience gained through previous pilot and demonstration operations, and that there is a great deal of knowledge on various abandonment techniques that have been proved suitable for CO_2 storage purposes. Recognition of this knowledge is not always evident, and in communicating with regulators and the general public, this level of understanding and confidence should be expressed. Future wells can be designed, drilled and abandoned taking into account the CO_2 storage operation, using state-of-the-art technologies.

What remains is for regulatory regimes to stipulate clear guidance on recommended best practices within their spheres of influence and operation, facilitating straight-forward start up and initialisation of projects.

The IEAGHG wellbore integrity network continues to provide a forum where industrial expertise and academic research can be brought together.

Storage Economics

Two IEAGHG studies in 2005 provided cost estimates for storage in Europe and North America, with mean reported costs per tonne in deep saline formations of €1 to €2.5 and US$13 respectively. (graphs of cost curves) The difference in these results reflects the European study using data from the highly permeable and relatively shallow Sleipner site. It is important to note that current technical and regulatory uncertainties provide obstacles to the meaningful prediction of CO_2 geological storage costs. IEAGHG is undertaking a new study on storage cost modelling in 2010 as further technical and regulatory developments have occurred.

Future Research

Major knowledge gaps and research areas in CO_2 geological storage highlighted by IEAGHG activities since 2004 include:

- Research into the related effects of pressurisation and brine displacement on storage in deep saline formations;
- Potential impacts for storage on groundwater resources;
- Improved regional estimates for Africa, Latin America and Asia (excluding China and Japan);
- Addition of representative range of case studies to aquifer DSF storage best practice manuals and incorporation of site characterisation procedures;
- Creation of best practice manuals for other storage scenarios – depleted gas fields, CO2-EOR and ECBM;
- Improvement of cost-effective monitoring strategies, including new techniques;
- Improve long term coupled modelling of geological storage, with improved understanding of geochemical processes;
- Quantification of potential leakage rates for storage sites;
- Health impacts of CO_2 release with/without impurities – especially long term effects and thresholds;
- Management of liability and requirements for, and duration of, post-injection monitoring.

IEAGHG will continue to focus on these and other knowledge gaps, through selected studies and the continued activities of the international research networks.

Appendix 1: IEAGHG Report Lists

Report Number	Report Title	Contractor	Publication Date
2005/01	Retrofit of CO_2 Capture to Natural Gas Combined Cycle Power Plants	Jacobs	January 2005
2005/02	Building the Cost Curves for CO_2 Storage: European Sector	TNO	February 2005
2005/03	Building the Cost Curves for CO_2 Storage: North America	Battelle	February 2005
2005/04	Assessment of the Costs and Enhanced Potential for Carbon Sequestration in Soils	Australian CRC for Greenhouse Accounting	February 2005
2005/06	NASCENT Report	BGS	March 2005
2005/07	Development of PPAP - Power Plant Assessment Program	IEAGHG/Gas Consult	December 2005
2005/08	A Review of Natural CO_2 Occurrences and Releases and their Relevance to CO_2 Storage	BGS	September 2005
2005/09	Oxy-combustion Processes for CO_2 Capture from Power Plant	MBEL	July 2005
2005/10	Low greenhouse gas emission transport fuels: the impact of CO_2 capture and storage on selected pathways	Chris Clark	August 2005
2005/11	CO_2 Storage by Mineral Carbonation	ECN	September 2005
2005/13	International Test Network for CO_2 Capture: Report on 8th Workshop	n/a	November 2005
2006/01	CO2 Capture in Low Rank Coal Power Plants	Foster Wheeler	January 2006
2006/02	Safe Storage of CO_2	Woodhill Frontier	January 2006
2006/03	Permitting Issues for CO_2 Capture and Geological Storage	ERM	January 2006
2006/06	Estimating the Future Trends in the Cost of CO_2 Capture Technologies	Carnegie Mellon University	February 2006
2006/07	Updating the IEA GHG Global CO_2 Emissions Database: Developments since 2002	n/a	March 2006
2006/08	CO_2 Capture as a Factor in Power Station Investment Decisions	Mott MacDonald	May 2006
2006/10	Reduction of CO_2 emission by means of CO_2 storage in coal seams in the Silesian coal basin of Poland (RECOPOL)	n/a	September 2006
2006/13	Near Zero Emissions Technology for CO_2 Capture from Power Plant	ECN	October 2006
2006/14	Environmental Impact of Solvent Scrubbing of CO_2	TNO	October 2006
2007/01	Environmental Assessment for CO_2 Capture and Storage	DNV	March 2007
2007/02	Role of Risk Assessment in Regulatory Frameworks for CCS	Monitor Scientific LLC	February 2007
2007/03	Potential Impacts of Leaks from Onshore CO_2 Storage Projects on Terrestrial Ecosystems	BGS	July 2007
2007/04	CO_2 Capture Ready Power Plants	E.ON	May 2007
2007/07	CO_2 Capture from Medium Scale Combustion Installations	Ecofys	July 2007
2007/11	Remediation of Seepage from CO_2 Storage Formations	API	August 2007
2007/12	Distributed Collection of CO_2	Gastec at CRE	August 2007
2007/13	Co-Production of Hydrogen and Electricity by Coal Gasification with CO_2 Capture	Foster Wheeler	September 2007
2007/14	Improved Oxygen Production Technologies	Rodney Allam	October 2007
2007/15	Post Combustion Carbon Capture from Coal Fired Plants – Solvent Scrubbing	IEA CCC	July 2007

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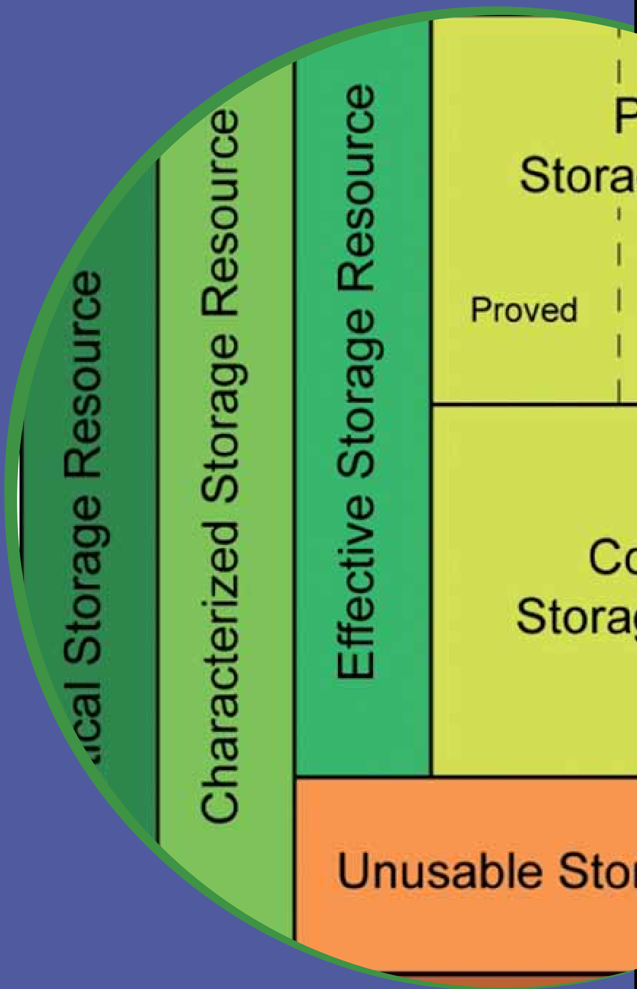
2007/15	Post Combustion Carbon Capture from Coal Fired Plants – Solvent Scrubbing	IEA CCC	July 2007
2008/02	An Assessment of the Potential for CO_2 Storage in the Indian Subcontinent	BGS	May 2008
2008/3	CO_2 Capture in the Cement Industry	Mott MacDonald	July 2008
2008/8	Assessment of Sub Sea Ecosystem Impacts	Rachel Dunk	March 2009
2008/9	Production of Hydrogen and Electricity with CO_2 Capture – Updated Economic Analysis	Foster Wheeler	August 2008
2008/10	Novel Approaches to Improving the Performance of Carbon Dioxide Capture	Innovaro	October 2008
2008/11	Reduction of Residential Carbon Dioxide Emissions through the Use of small Cogeneration Fuel Cell Systems	ForschungZentrum Jülich	Nov 2008
2008/12	Aquifer Storage – Development Issues	CO2CRC	December 2008
2008/13	Carbon Dioxide Capture and Storage in the Clean Development Mechanism: Assessing market effects of inclusion	ERM	December 2008
2009/01	Storage in Depleted Gas Fields	Poyry, BGS & Element	July 2009
2009/02	Post Combustion Capture – Solid Sorbents and Membranes	Clean Coal Centre	April 2009
2009/03	Upgraded Calculator for CO_2 Pipeline Systems	Gastec UK/AMEC	Feb 2009
2009/06	Safety in Carbon Dioxide Capture, Transport and Storage	UK HSL Laboratory	June 2009
2009/8	Long Term Integrity of CO_2 Storage – Well Abandonment	TNO	July 2009
2009/9	Techno-Economic Evaluation of Biomass Fired or Co-Fired Power Plant with Post-Combustion CO_2 Capture	Foster Wheeler	July 2009
2009/10	CCS Site Selection and Characterisation Criteria	Alberta Research Council	July 2009
2009/12	CO_2 Storage in Depleted Oil Fields	ARI	July 09
2009/13	Development of Storage Coefficients for Carbon Dioxide Storage in Deep Saline Formations	EERC	October 2009
2009/14	Evaluation of Novel Post-Combustion CO_2 Capture Solvent Concepts	SINTEF Chemistry and Materials	November 2009
2009/15	OPEC-IEA GHG CCS workshop for scientists and professionals in OPEC Member Countries	-	December 2009

Evaluating technology options to mitigate greenhouse gas emissions



IEA Greenhouse Gas R&D Programme

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