Carbon Dioxide Capture for Storage in Deep Geologic Formations – Results from the CO_2 Capture Project

Capture and Separation of Carbon Dioxide from Combustion Sources

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Volume 1

ELSEVIER
2005

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Kidlington, Oxford OX5 1GB
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84 Theobalds Road
London WC1X 8RR
UK

First edition 2005

Library of Congress Cataloging in Publication Data
A catalog record is available from the Library of Congress.

British Library Cataloguing in Publication Data
A catalogue record is available from the British Library.

ISBN: 0-08-044570-5 (2 volume set)

Volume 1: Chapters 8, 9, 13, 14, 16, 17, 18, 24 and 32 were written with support of the U.S. Department of Energy under Contract No. DE-FC26-01NT41145. The Government reserves for itself and others acting on its behalf a royalty-free, non-exclusive, irrevocable, worldwide license for Governmental purposes to publish, distribute, translate, duplicate, exhibit and perform these copyrighted papers. EU co-funded work appears in chapters 19, 20, 21, 22, 23, 33, 34, 35, 36 and 37. Norwegian Research Council (Klimatek) co-funded work appears in chapters 1, 5, 7, 10, 12, 15 and 32.

Volume 2: The Storage Preface, Storage Integrity Preface, Monitoring and Verification Preface, Risk Assessment Preface and Chapters 1, 4, 6, 8, 13, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33 were written with support of the U.S. Department of Energy under Contract No. DE-FC26-01NT41145. The Government reserves for itself and others acting on its behalf a royalty-free, non-exclusive, irrevocable, worldwide license for Governmental purposes to publish, distribute, translate, duplicate, exhibit and perform these copyrighted papers. Norwegian Research Council (Klimatek) co-funded work appears in chapters 9, 15 and 16.

♾ The paper used in this publication meets the requirements of ANSI/NISO Z39.48-1992 (Permanence of Paper).
Printed in The Netherlands.

Carbon Dioxide Capture for Storage in Deep Geologic Formations, Volume 1
D.C. Thomas and S.M. Benson (Eds.)

Chapter 38

CAPTURE AND SEPARATION TECHNOLOGY GAPS AND PRIORITY RESEARCH NEEDS

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ABSTRACT

This final chapter summarizes the major conclusions and results of the CCP's capture and separation technology development projects. It provides a look forward to Phase II of the CCP and future research needs.

Separation technology challenges include:

- A fundamentally different approach to post-combustion capture. The CCP saw some potential for novel integrated approaches for separation with advanced solvents.
- Pre-combustion decarbonization to make hydrogen at very large scale as a precursor to a hydrogen-based combustion system. A systems analysis and comprehensive approach to the major components of a hydrogen fuel system are needed.
- Oxygen-fired combustion. Combustion in either oxygen-enriched air or pure oxygen offers the advantage of reduced NO_x and SO_x emissions while producing a highly concentrated CO_2 stream for sequestration. Oxygen production is a major need and challenge – at the needed scale and costs. Chemical looping combustion that combines oxygen production with combustion may have great promise. It needs comprehensive study to determine its future potential.

Public policy, incentives and regulatory activities by the various governments will be a substantial challenge for those attempting to sequester CO_2. Worldwide governmental actions must be monitored and accounted for in future technical developments.

INTRODUCTION

The volume you have just studied describes the work on capture and separation technologies completed through the efforts of the CCP team and contractors to the project during the past 4 years. It represents the combined efforts of several hundred people from around the world who completed over one hundred studies in a very short period of time.

Some of the studies were cut short—even before they might have produced good results—because of the basic premise of the CCP. The CCP was intended to jump-start technology development and to identify commercially feasible technologies that could be implemented in the next decade. It was not intended to be a venue for exploratory and fundamental research that might deliver commercially ready technology decades in the future.

Some studies published here were "unsuccessful" because they did not lead to a commercialisable process by the definitions used in the CCP. That does not mean that the technology has no value, it means that it would not be ready for use by 2010, it might only work in a few niche applications, or could not meet the high cost reduction standards set at its current stage of development.

This chapter will identify areas where further research is needed and will outline the tentative goals of the CO_2 Capture Project—Phase 2 (CCP2) program that will follow on. The CCP leadership hopes that the areas noted here will provide opportunities and encouragement for researchers in their future work.

The CCP have uncovered the potential for huge cost savings in the capture of CO_2 in a relatively short span of time by bringing industrial knowledge, skills, and management capability to drive this important technology along at an unprecedented speed. Potential cost reductions of about 60% compared with base case technology (amine scrubbing) were attained in a little over 2 years. These results (Figure 1) could not have been achieved without the help and dedication of the over 70 contracting organisations who performed the work in partnership with the CCP technical teams. The CCP is confident that the pace of delivery and further cost reductions will be identified in CCP2.

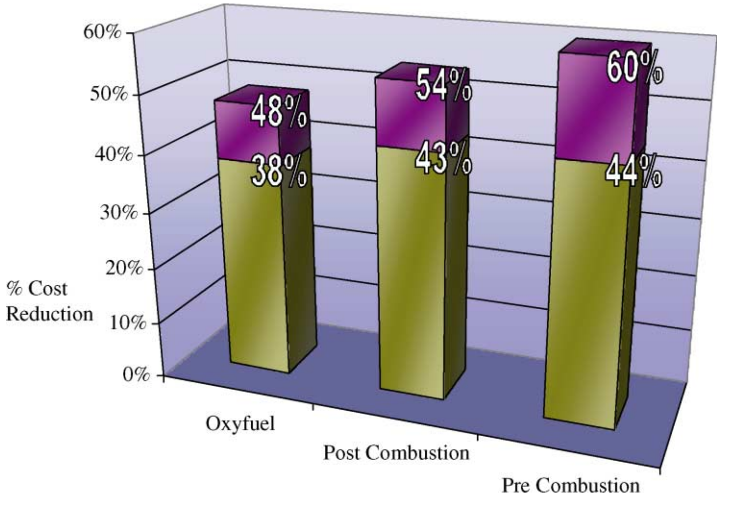

Figure 1: CCP Capture—CO_2 Avoided Cost Reductions (Preliminary data, ±30% cost estimates, top two CCP technologies cost reduction data points).

CO_2 CAPTURE PROJECT—PHASE 2 PLANS

The CCP program is continuing with most of the current team in place. Current membership is: BP, ChevronTexaco, Eni, Hydro, Shell and Suncor. Negotiations are taking place with a number of other potential participants. The project is likely to open up to a broader group of participants through associate memberships. Funding is confirmed from the Norwegian Government and applications have been made, or will be made, to the United States Government and to the European Community.

The major goals of the CCP2 program going forward are:

1. International industry and government partners cooperatively direct and fund the development of CO_2 capture and storage technologies with the aim of advancing the science and expanding the potential scope of implementation.
2. Identify best practices and reduce uncertainties associated with geological storage of CO_2.
3. Identify and develop technologies to reduce the cost of capture of CO_2 emissions by 50–75% from the 2000 baseline:
   a. Achieve cost target of capture and storage of \$20–30 per ton of CO_2
   b. Include cost target in terms of dollars per KWHR power generated
4. Increase public acceptance and awareness of CO_2 capture and storage.

The objectives are then to:

- Further develop CO_2 capture technologies with aim to reduce cost and technical uncertainties prior to demonstration through parallel R&D studies with sequential pilots to be evaluated on a case by case basis. The CCP will stop technology development when success is achieved.
- Develop industry guidelines for secure, cost-effective CO_2 geological storage; addressing issues such as site selection, risk assessment, well integrity, monitoring, verification and abandonment
- Establish an extended network including resources to CCP for CO_2 storage demonstrations.

Success factors used to measure performance against objectives for CCP2 include:

- One or more capture technologies is available to pilot (with at least 50% cost reduction from 2000 baseline) in retrofit and new-build applications.
- Delivered a strategy for the future demonstration of at least one capture technology.
- A set of proposed industry standards has been created for storage, monitoring, verification and abandonment.
- Geological storage is accepted in emissions trading schemes (i.e. EU ETS 2008-12).
- A network is established for information sharing among storage demonstrations
- $>40\%$ of CCP2 cash spend is provided by co-funders to demonstrate the partnership between governments and industry.

This means that the CCP2, if successful, will have:

- Progressed CCP1 (CO_2 Capture Project Phase 1) technologies to improve performance and reduce uncertainties (of timing, development risk and cost);
- Understood and included promising new technologies;
- Developed by the end of 2004 an R&D strategy for pilot testing, such that technologies are ready for sequential piloting when the time is right (market and participant-driven);
- Developed a portfolio of technologies on parallel tracks

The expected schedule and timeframe are to continue with ongoing R&D in 2004, reducing uncertainty on scale-up and other issues identified as being in need of more work in CCP1. At the same time, the teams will begin detailed workscope preparation for pilot scale performance tests to be considered on a case by case basis as results from the R&D phase for each technology dictate. The economic model that was applied with great success in CCP1, enabling us to evaluate and compare technology performance on a common basis, will be applied as technologies are tested in further project stagegates. It will also be made available for other projects outside the CCP to enable their performance to be assessed on the same basis. Some pilot tests may commence during CCP2 which has a tentative end date of 31st December 2008.

The plan is to issue requests for proposals in these areas, for R&D in the first instance and pilot testing that could follow if R&D success criteria are met. The proposals and contractors will be matched to the appropriate funding opportunity. For new ideas or technologies that have been developed outside of CCP1, the plan is to compare them on the same basis that CCP1 technologies were judged and any that are competitive will be considered by the Executive Board for inclusion in the CCP2 program.

TECHNOLOGIES NEEDING MORE FUNDAMENTAL RESEARCH AND IN-DEPTH STUDY

Certain technologies that the CCP supported but were dropped because they were not likely to meet our short-term goals may prove valuable in future CO_2 mitigation options with further development. These include:

- *Kvaerner membrane*. The membrane as tested allowed a small amount of solvent to leak through. This meant that an additional plant would have to be constructed to deal with that small amount of solvent. New

membranes that do not let solvent pass through would improve performance economics considerably and may bring this technology back in the race.
- *Sulphur tolerant membranes for separating hydrogen from CO_2*. The aim was to develop sulphur tolerant membranes for use in the water–gas shift process that also had very high permeability to hydrogen. Some membranes developed were sulphur tolerant but did not have the needed hydrogen flux rates and so were abandoned. If membranes are developed that can overcome this problem, a whole new area of application for the technology which has already demonstrated high potential cost reductions for non-sulphur (sweet) syngas could open up for sulphur containing (sour) sour service.

SEPARATION TECHNOLOGY GAPS AND CHALLENGES

The CCP attempted a comprehensive look at pre-commercial and commercial technologies that might be applied to CO_2 capture and storage. Even given the excellent work and results of our teams, there is still a need for investment in:

Post-combustion separation and capture. The huge investment and inventory of existing plants emitting CO_2 means that separation of CO_2 from flue gases will have to be commercially practiced at some time. A fundamentally different approach to post-combustion capture is needed. Areas where we saw potential are novel integrated approaches to the process system design coupled with new advanced solvents.

Pre-combustion de-carbonisation—hydrogen. Large-scale hydrogen production will bring with it the need for a hydrogen infrastructure and the systems to make hydrogen fuelling practical. A systems analysis and comprehensive approach to the major components of the hydrogen fuel system are needed. Areas in which we believe effort is required are:

- Hydrogen/CO_2 separation membrane production at scale and life cycle assessment;
- Support systems for these membranes and the reactors to carry them;
- Conversion of gas turbines for hydrogen firing;
- And in all areas sulphur tolerance to expand the range of fuel applications.

Oxyfiring. Combustion in either oxygen-enriched air or pure oxygen offers the advantage of reduced NO_x and SO_x production along with the described characteristics for producing a highly concentrated separated CO_2 stream.

The CCP1 chemical looping combustion program results were highly encouraging as this technology could be applied to large-scale heaters and boilers. Promising materials have performed well in over 300 h of continuous testing. Particle performance testing is needed to understand the potential full-scale attrition rate and the costs for replacement and disposal of spent particles. The search for cheaper particles or particles with low attrition rates should continue. Application of chemical looping technology to gas turbines would require the development of effective and economic filtration of the fluid stream supplying the turbine. A detailed economic feasibility study of chemical looping combustion processes is recommended before significant further development is undertaken. This study is not in the scope of the CCP2 program.

FUEL SOURCES: COAL, OIL, GAS

The CCP has been largely focused on petroleum and chemical industry systems—because of the areas of expertise in the team and because of the focus on geologic storage. Since coal is, and will remain, a key fuel for electricity generation for at least another century; it is necessary to engage the coal industry in development of capture and storage systems. Bringing these diverse stakeholders together is a major challenge for the team. Areas where common effort would be beneficial are:

- membranes for hydrogen and CO_2 separation (including sulphur tolerant membranes);
- a common approach to economic performance assessment;
- understanding the benefits of oxyfiring and issues around heater and boiler conversion;

- retrofitting any CO_2 capture technology;
- transportation issues;
- monitoring, verification, and public acceptance of geologic storage.

POLICY, INCENTIVES, AND REGULATORY CLIMATE

Commercialisation of CO_2 capture and storage systems will be expensive and add to the economic and political risk for all parties. Parallel to its technology development, the CCP should continue its engagement of policy makers and other stakeholders to ensure an economic, and stable future for CO_2 storage. Governments and regulators need help in understanding the technology options provided by CCP, and other, research programs to enable them to make good choices for demonstration projects and, in the longer term, full-scale geologic CO_2 storage. They also need assistance in understanding their options in the context of eligibility of geologically stored CO_2 for credits in approved trading schemes. This acceptance may be crucial to help bridge the wide economic gap that capture and storage projects face today. It also may be vital to accelerating the rate at which industry can respond to the climate stabilisation challenge.

CONCLUSIONS

We have made great progress but there are real gaps in our knowledge. Key questions include:

- Can the laboratory performance of hydrogen–CO_2 separation membranes be maintained in large scale testing and manufacture?
- Can CO_2 capture technologies be retrofitted to existing operations in a practical way from both cost and operability viewpoints?
- Can existing gas turbines be fitted for hydrogen firing service in a practical way?
- Can chemical looping combustion technology be acceptable to power generators in boiler and heater application?
- How much further can we push the limits on post-combustion capture technology?

RECOMMENDATIONS

- The CCP recommends that urgent consideration be given to scale up and manufacture hydrogen separation membranes with CO_2 capture. In particular, durability testing and membrane support development are needed. At the earliest sensible opportunity, perform large scale demonstration tests to uncover any weaknesses in the technical approach and to identify further opportunities for cost savings.
- One of the largest costs in post-combustion CO_2 capture is the heat exchange processes needed to cool the flue gas to the operating temperature range of current commercial solvents. Significant opportunities exist to re-examine the approach to heat recovery and to design integrated systems while continuing to develop improved solvents.
- Chemical looping combustion technology offers considerable cost savings for fired heaters and boilers. It provides a second benefit through much reduced NO_x production and emissions. However, the particle strength needs to be improved and attrition rates for particles must be established through exhaustive testing to ascertain their stability and to possibly lead to further cost reductions.

ACKNOWLEDGEMENTS

The author would like to acknowledge the help and support of the European Commission, Departments of Transport and Energy and of Research. The Norwegian Government through the Norwegian Research Council Klimatek Program and the US Department of Energy, through the NETL Coal Sequestration Program for co-funding the research recorded in these volumes and the help and feedback on project progress from the program managers, Dennis O' Brien, Vassilios Koughianis, Hans Roar Sorrheim, Philip Goldberg and David Hyman.

Special acknowledgement goes to the CCP Team Leads who coordinated the study areas reported: Odd Furuseth (Statoil, post-combustion capture). Henrik Andersen (Hydro, pre-combustion capture), Ivanno Miracca (Eni, oxyfiring) and Torgeir Melien (hydro, economic modelling). Scott Imbus (Chevron texaco, SMV), Arthur Lee (Chevron Texaco, policy and incentives) and Vello Kuuskraa (ARI, TAB). The CCP Project Controller Stuart Green deserves special recognition for not only providing financial and procurement support but also for coordinating report delivery and maintaining the project schedule. Thanks also go to the CCP Executive Board for their continued hard work and commitment to the CCP's success. A final thank you to David C. Thomas (ARI) and Sally Benson (Lawrence Berkley National Laboratory) for their hard work in editing these volumes.