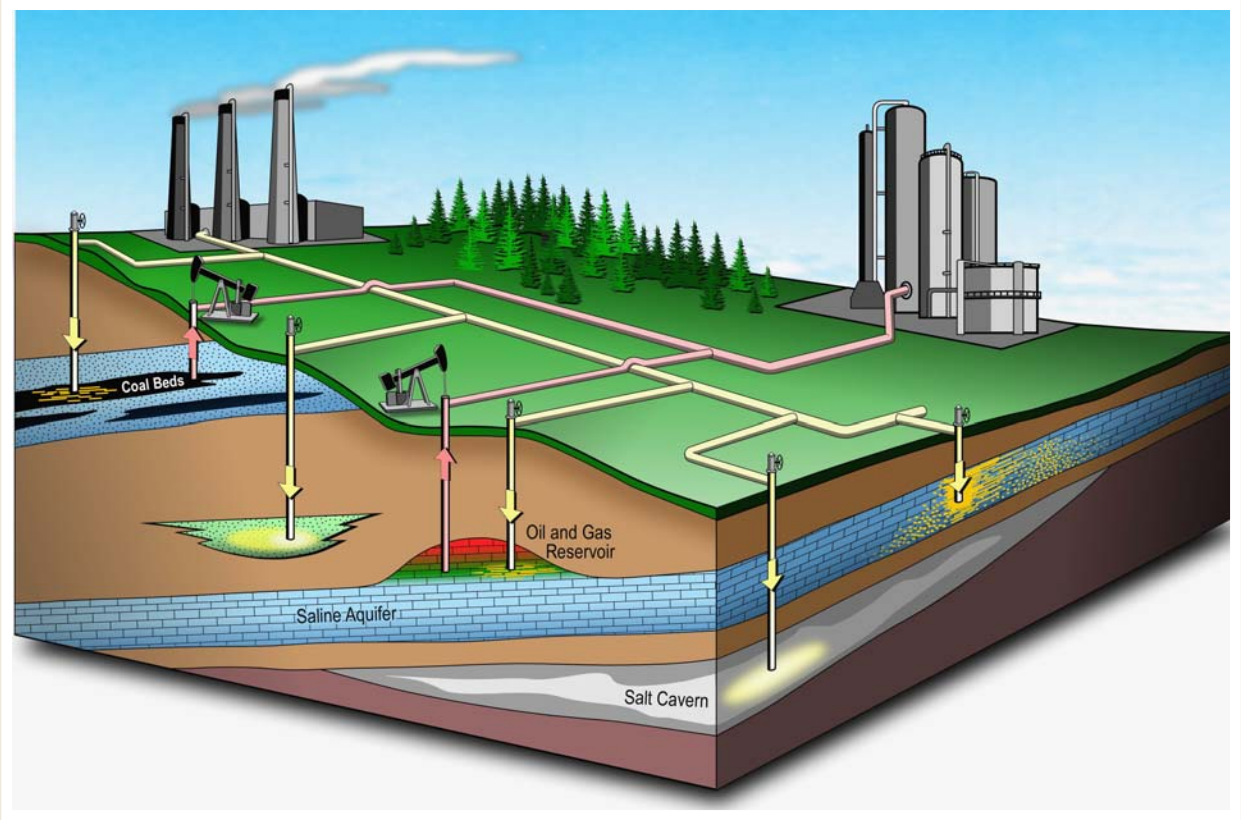
Carbon Dioxide Capture and Storage: A Compendium of Canada's Participation



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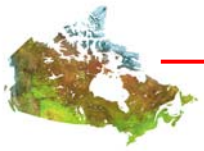

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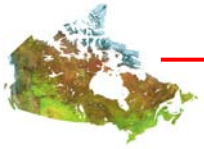

CARBON DIOXIDE CAPTURE AND STORAGE: A COMPENDIUM OF CANADA'S PARTICIPATION

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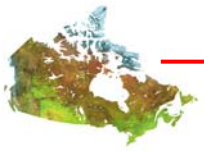


EXECUTIVE SUMMARY

The capture and storage of CO_2 from point sources is an increasingly attractive option for addressing global greenhouse gas (GHG) emissions. In 2005, a major study commissioned by the Intergovernmental Panel on Climate Change (part of the United Nations Framework Convention on Climate Change) was completed, confirming this global interest. Until now, this mitigation option was not explicitly recognized by the UNFCCC. Negotiations to do so are under way.

The potential value of CO_2 capture and storage (CCS) to Canada is enormous because of the proximity of large point sources of CO_2 and potential geological sinks for CO_2. For this reason, Canada has, for the past 15 years, been very active in exploring the opportunities for CCS, in developing and testing techniques and technologies to implement it, and in examining the associated policy, regulatory, environmental, and public education issues. Canada is now actively promoting the inclusion of CCS within the UNFCCC.

To help the community engaged in CCS work in Canada to identify gaps, set priorities, and promote cooperation, and to inform Canada's representatives in international discussions of the extent of Canada's engagement, the Office of Energy R&D of Natural Resources Canada proposed a broad compilation of current work, including not only scientific and engineering projects, but also projects that examine economic, implementation, public education and outreach, and regulatory issues. The key players in Canada's CCS investments were to be identified and their roles described.

This report seeks to compile all Canadian activity in CCS. The report has three main components. The first provides brief overviews of the principal Canadian organizations engaged in CCS and the international organizations involved in CCS in which Canada (or Canadian organizations) plays an active role. A total of 83 organizations are so featured. The second component features summaries of specific projects under way (as of the end of 2005) or recently completed (2003 or later); 126 projects are identified. And finally, five documents that are key to Canada's strategy of developing capacity in CCS are listed.

Of the 83 organizations described, 14 provide coordination and planning of CCS activities (6 of them within Canada and 8 of them internationally); 25 are the principal research performers in CCS in Canada (including 8 universities with substantial engagement); 23 are companies who are developing, testing, using, or analyzing the effects of CCS technologies; 8 are federal and provincial government agencies involved in aspects other than research performance; and 13 are government programs supporting CCS projects (see Figure 1).

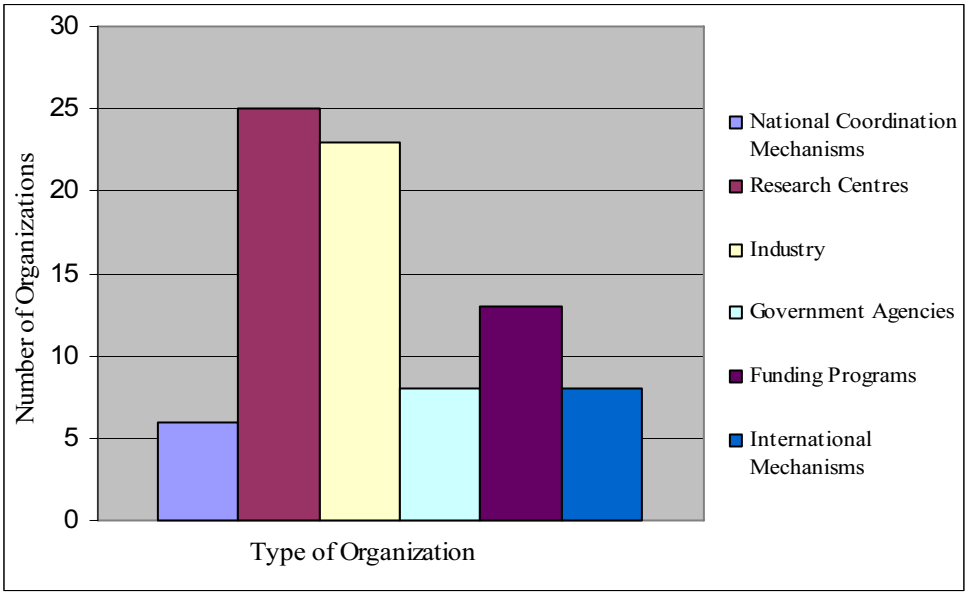


Figure 1. Distribution of organizations involved in CO_2 capture and storage

Of the 126 projects, the most frequent topic is CO_2 capture (54 projects), followed by CO_2 storage (49 projects). A number of other subjects have much smaller frequencies: sources & sinks (7); and economic, social, and regulatory projects (9)). Just 1 project addresses transportation of CO_2. Another 6 projects either fit multiple topics (3) or were difficult to classify (3) (see Figure 2).

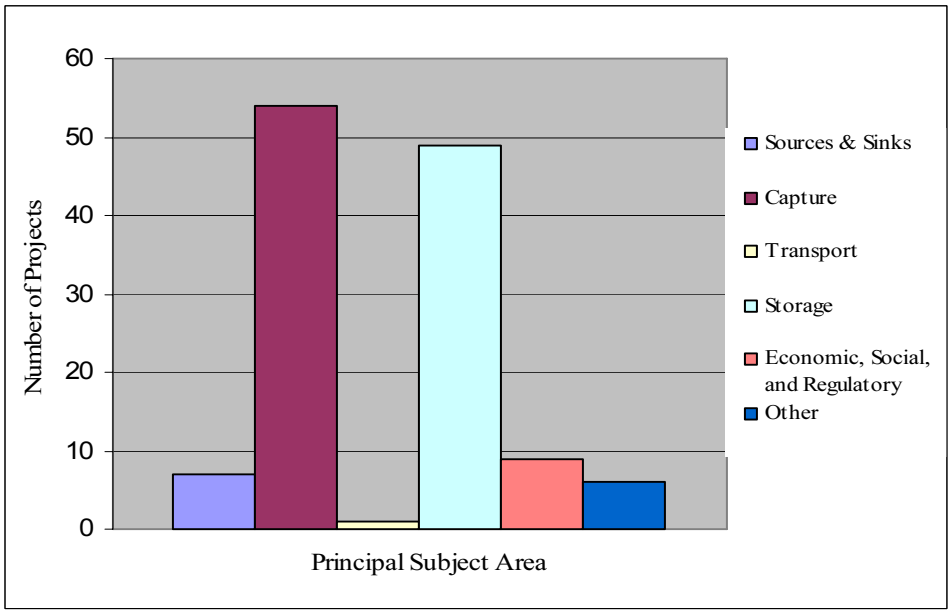


Figure 2. Distribution of projects involved in CO_2 capture and storage topic areas

Many of the projects involve multiple performers and multiple funders. However, when categorized by lead performer, 59 of the projects are conducted or led by universities; 42 by government research agencies (including provincial research organizations); 23 by industry (a category that includes any for-profit company); and 2 by Non-Government Organizations (NGOs) (see Figure 3).

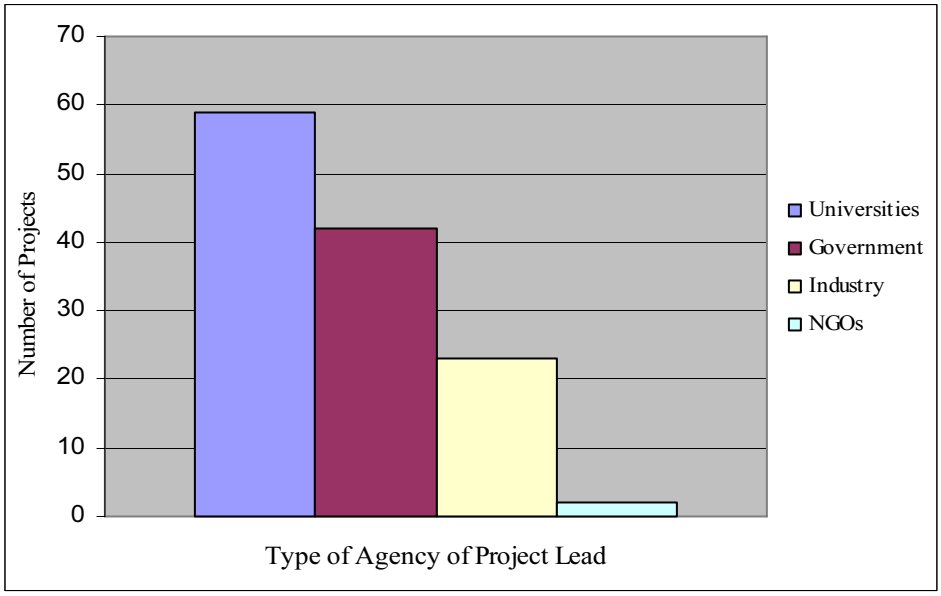
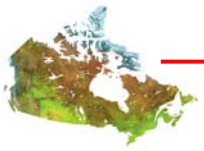


Figure 3. CO_2 capture and storage projects categorized by lead performer

Five documents that are essential to setting the priorities for CCS in Canada are also described.

Each entry in this compendium briefly describes the organization or activity, highlights the role it plays in CCS, identifies and provides links to contacts for additional information, and for projects, sets out the duration, funding, and participants.

Organizations devoted to some aspect of CCS, and related projects, are growing rapidly in number. A major effort was made to ensure the completeness and accuracy of this compendium, but given the dynamic nature of this field and the number of organizations engaged, some elements may have been missed. Nonetheless, it is hoped that this document will be of broad use, not least to demonstrate the resources that the Canadian energy community is prepared to invest in this promising way of reducing Canada's CO_2 emissions.



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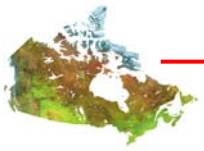

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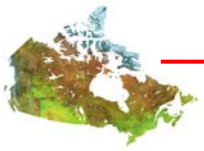

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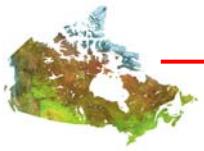

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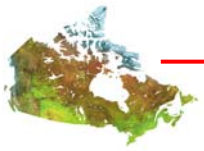
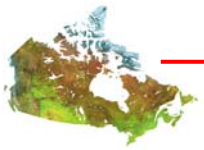




INTRODUCTION

The observed increase in the concentration of CO_2 and other greenhouse gases (GHGs) in the atmosphere has given rise to growing concerns about the potential for increasing global temperatures and related climatic impacts over this century and more. The international community, especially through the Intergovernmental Panel on Climate Change (IPCC), has pointed to increases in anthropogenic CO_2 as a principal driver for the observed growth of atmospheric CO_2 concentrations. Through the Kyoto Accord, developed under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC), most developed nations have committed to reduce their CO_2 and other GHG emissions. Canada, as a signatory to the Kyoto Accord, has initiated a number of activities aimed at lowering Canada's GHG emissions in both the period covered by the Kyoto Accord (up to 2012) and beyond. These initiatives are largely focused on the energy sector, which accounts for the vast majority of GHG emissions.

There are three principal strategies by which CO_2 emissions from the energy sector can be significantly reduced:

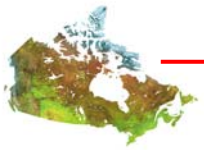
1. Reduce energy demand through a combination of energy conservation and energy efficiency measures
2. Reduce the carbon intensity of energy production through greater reliance on lower-carbon energy sources such as natural gas and non-carbon sources such as nuclear and renewable energy sources.
3. Capture the CO_2 emitted from carbon-based energy production processes and store this CO_2 for long periods away from the atmosphere.

This report focuses on the last of these options.

The capture of CO_2 from point sources and its injection into geologic formations or its fixation in other media ("CO_2 capture and storage" [CCS]) is an increasingly promising option for reducing CO_2 emissions in Canada and globally. Since the late 1980s, Canada has been actively investigating the feasibility of enabling the capture of CO_2 from large point sources and the technologies to do so, with subsequent disposal, storage, or sequestration in geological structures and other media. Canada has been and continues to be regarded as a world leader in the associated technologies and infrastructure.

Canada and a few other countries have been active in CCS for some time, but it is only recently that the international community, through the IPCC, has begun to recognize the full potential of CCS to contribute in a major way to combating global warming. Indeed, over the last year or so, the potential of CCS has been under close study by a specially commissioned working group of the IPCC. The IPCC Special Report on CO_2 Capture and Storage was discussed at a September 2005 meeting of the IPCC in Montreal and was tabled at the Conference of the Parties (COP 11) in Montreal in November and December 2005. Although significant progress was made at COP 11, the full acceptance of CCS under the Kyoto mechanisms is still under discussion.

Canada's representatives at these and subsequent meetings will be involved in discussions about the potential for CCS and how it should be dealt with under the UNFCCC. To do so effectively, it is vital that our delegates be aware of the full range of Canadian engagement in all aspects of CCS. In support of this and to help the community engaged in CCS work in Canada to



identify gaps, promote cooperation, and set priorities, the Office of Energy Research and Development (OERD) at Natural Resources Canada (NRCan) set out to compile a summary of Canadian activities and players in the field of CCS. The scope of the compilation was to be broad, including not only scientific and engineering projects, but also those that examine economic, implementation, public education and outreach, and regulatory issues. Moreover, the key players in Canada's investments in CCS were to be identified and their roles described.

This report is the resulting compilation.

Acknowledgments

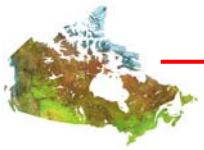
The authors (John F. Legg and Frank R. Campbell) owe a great measure of thanks to the many people who contributed to the development of this compilation. First of all, we must thank OERD, whose staff identified the need for this document and provided extensive guidance regarding its scope and structure. We would like to especially thank Dubravka Bulut and Kelly Kishiuchi of OERD for their help and support throughout the project, and Graham Campbell for his oversight of the project.

But we have to save our special thanks for all the individual contributors who responded to our many requests for information, comments, corrections, and approvals. This report is a testimony to their foresight, innovation, persistence, and curiosity, but most of all to their success in bringing CCS from a radical concept to near commercial application in a very short time. In many cases, you will be able to identify these individuals from the contact names that we include. Nevertheless, the reader should be aware that the work reflected herein is usually the product of teams. Each member of those teams has earned a mention for his or her contribution; however, we chose to not attempt an exhaustive listing of all contributors, and so only principal contacts are shown.

Structure of Document

This document is organized into four principal parts: the first catalogs and describes the major "players" involved in Canadian CCS; the second catalogs and describes each currently active or recently completed (roughly since 2003) science and technology (S&T) project; the third summarizes economic, regulatory, and public outreach projects; and the fourth describes a number of overview documents that have particular impact on Canadian activities. The first three parts are further subdivided by the types of players and the project subject areas. Each subdivision is assigned a sequential number, and each entry within a subdivision is assigned a second sequential number. Thus, players are identified as "Org *a.b*", where *a* is the number of the subdivision, and *b* is the number of the organization within the subdivision. Similarly, projects are identified as "Proj *a.b*". Documents are identified simply as "Doc *a*". The overall structure is best appreciated by examining the Contents page.

We have tried to make it relatively easy to navigate the almost 200 separate entries in the document. Once again, the Contents page (TOC) is key. All titles in the TOC are "linked" to the corresponding player, project, or document summary. When you are viewing the TOC, a "Ctrl + left click" on a title will bring you directly to the location of the relevant entry in the body of the document. Each player entry contains references to the projects with which that player is involved, if any. Similarly, each project contains references to the relevant players. However, these references are not themselves "linked". To link to a particular project or player, you will have to return to the TOC.



Returning to the TOC takes a little more work. If you are running Word 2003 or XP, pull down the Tools menu, and select Customize. In the dialog box that then appears, select the Toolbars menu. Scroll down until you see a check box marked "Outlining". Select the check box, and click Close. You should now see a new line of tool icons at the top of the page. The one that you need for navigation purposes is the icon depicting a document page with an upward curved arrow. Clicking this icon will bring you to the end of the TOC. You can then scroll to the location you want within the TOC.

Caveats

The authors have made a determined effort to ensure that

- the compilation is exhaustive. Although an exhaustive listing was the objective, so much activity is underway that we have almost assuredly not included all activities and players. The field is a dynamic one, and new projects are taking shape all the time. We trust that gaps in the coverage are not many and certainly not so numerous as to distort the overall picture of Canadian activity in CCS.
- entries are accurate and reasonably complete. In all cases, we tried to solicit feedback about the quality of the summaries from the organizations and individuals cited. We were not always successful. Summaries for which feedback could not be obtained are identified by an asterisk in front of the identifying number. In a few cases, we were unable to obtain sufficient information to allow a decent summary to be drafted. Where a summary is unavailable, we have provided an unsorted list of project titles and possible contacts at the end of the appropriate section (Section 2). In some other cases, key information could not be acquired, and the relevant data fields are therefore blank. Finally, we also exercised some editorial discretion on specific text, and so the wording may be slightly different from that proposed by project proponents; however, we have tried to stay true to the basic descriptive material provided.

A word about verb tenses: In the project descriptions, the reader will note the use of a variety of verb tenses. The future tense is used often, even for projects already completed, because in many cases the authors of this report relied on descriptive information contained in proposals. Proponents left most of these descriptions unchanged during their reviews, and so there was no confirmation that all proposed work had been completed successfully. Consequently, the tenses were left as they appeared in the proposal. In other cases, proponents revised project descriptions to reflect actual outcomes, in which case the past tense was used. The authors regret any confusion this may cause.

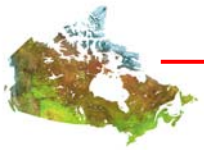
Acronyms and Initialisms

The meaning of each major acronymn and initialism used in this document appears here.

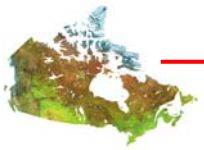
APEC	Asia–Pacific Economic Cooperation
AST	Advanced separations technology
CBM	Coalbed methane
CCS	CO_2 capture and storage

CDM	Clean development mechanism
COP	Conference of the Parties [to the Kyoto Protocol]
CSLF	Carbon Sequestration Leadership Forum
ECBM	Enhanced coalbed methane
EHR	Enhanced hydrocarbon recovery
ENGO	Environmental non-governmental organization
EOR	Enhanced oil recovery
GAMS	General Algebraic Modelling System
GHG	Greenhouse gas
GIS	Geographic information system
Gt	Gigatonne
GWP	Global warming potential
IEA	International Energy Agency
IEA GHG	International Energy Agency Greenhouse Gas R&D Programme
IGCC	Integrated gasification combined cycle
km	Kilometer
km^2	Square kilometer
kmol	Kilomole
kt	Kilotonne
m^3	Cubic meter
MDEA	Methyldiethanolamine
MEA	Monoethanolamine
MOP	Meeting of the Parties [to the Kyoto Protocol]
Mt	Megatonne
NGO	Non-governmental organization
NRC	National Research Council
R&D	Research and development
S&T	Science and technology
SOFC	Solid oxide fuel cell

UNFCCC	UN Framework Convention on Climate Change
WCSB	Western Canadian Sedimentary Basin
ZET	Zero emissions technology



PART A: ORGANIZATIONS



1. COORDINATION AND PLANNING—CANADA

Org 1.1: Canadian CO_2 Capture and Storage Technology Network

What is it? The Canadian CO_2 Capture and Storage Technology Network (CCCSTN) is an extensive, voluntary network of people and organizations working on CCS development in Canada. The scope of the network includes economic and environmental issues relating to CCS.

Role Played in Canadian CCS CCCSTN participants use the network to exchange information and to facilitate coordination of their research, development, and demonstration project initiatives.

CCCSTN represents Canadian projects at international and national events hosted by such organizations as the Australian Cooperative Research Centre for Greenhouse Gas Technologies (CO_2 CRC), the Carbon Sequestration Leadership Forum (CSLF), the International Energy Agency (IEA), the Intergovernmental Panel on Climate Change (IPCC), and so on.

Description Participation in the network is open to the entire Canadian CCS community, including industry, academia, and government. International collaboration is active and encouraged.

CCCSTN is funded by the federal government. There is no membership fee. Resources for conferences and other activities are provided in-kind from network members.

Many of the participants have worked on major documents that, although not formally a product of the network, reflect the views of the Canadian CCS community. These include a CCS technology roadmap [Doc 1.1]; *CANiCAP,* a CO_2 capture "pillar document" to the Canadian roadmap [Doc 1.4]; *CANiSTORE*, a CO_2 storage "pillar document" to the Canadian roadmap [Doc 1.3].

National coordination and a secretariat are currently provided by the federal government's CANMET Energy Technology Centre–Ottawa [Org 3.1].

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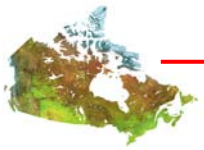
The CCSTN web site is www.co2network.gc.ca.



Org 1.2: EnergyINet Inc.

What is it? EnergyINet is a Canadian network that brings industry, researchers, and government together to help develop new environmentally responsible hydrocarbon and renewable energy technologies.

Role played in Canadian CCS The corporation includes a CO_2 Management Program (principally storage) and a Clean Coal Program (principally capture).

Description EnergyINet is a group of professionals with a head office in Calgary and a Saskatchewan office in Regina. The corporation works to be a facilitator or a neutral place where organizations can come together to work on common issues.

- At present, EnergyINet focuses on six programs related to
- development of alternate and renewable energy.
- enhanced value of bitumen and heavy oil.
- demonstration and use of new clean coal technologies.
- reduction of greenhouse gas and other emissions.
- maximizing recovery of conventional and unconventional oil and gas.
- treatment, recycling, and reduction of water consumption.

To these ends, the corporation maintains an overarching vision and strategy in its role of facilitator and collaborator and in creating links to build a roadmap for research and commercialization. The corporation also serves as a global technology information clearinghouse. Finally, the corporation invests directly in research, development and technology commercialization.

EnergyINet's Clean Coal and Carbon Innovation Program (CCCIP), with an interest in CO_2 capture, has recently merged with the Canadian Clean Power Coalition [Proj 3.6]. CCPC plans to demonstrate the commercial feasibility of CO_2 capture from a coal-fired power plant.

EnergyINet's CO_2 Management Program covers systems for CO_2 capture and transport; identification and characterization of geological storage sites; new technologies for geological storage; and technology and guidelines to verify storage.

EnergyINet is guided by a board of directors consisting of senior managers drawn from federal and provincial energy departments, major utilities, oil and gas producers, and major research centres.

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The EnergyINet web site is www.energyinet.com.

Org 1.3: Petroleum Technology Alliance Canada

What is it? The Petroleum Technology Alliance Canada (PTAC) is a not-for-profit industry association that promotes collaborative research and technology in the Canadian upstream conventional oil and gas industry.

Role played in Canadian CCS Within PTAC, a newly-formed CO_2 Enhanced Hydrocarbon Recovery (EHR) Steering Committee offers members a forum for collaboration.

Description The CO_2 EHR Steering Committee's mandate covers the use of CO_2 to enhance production of oil and gas reservoirs, leaving the CO_2 sequestered in the geological formation.

The role of the Steering Committee reflects the role of PTAC as a whole. The committee provides a forum on CO_2 EHR–related innovation, research and technology, priorities, needs and challenges, and identification of barriers and opportunities.

Under the guidance of the Steering Committee, and as funding permits, PTAC will facilitate the search for new or improved technologies and will foster their development through pilot testing, if required. Furthermore, PTAC will organize demonstration projects, working groups, Requests for Technology (RFTs), technology or innovation case studies, workshops, forums, conferences, and technology information sessions as required to deliver the results of development work to industry.

Members of the Steering Committee (as of April 2005) were Alberta Energy Research Institute, Air Liquide, Alberta Geologic Survey (AEUB), Alberta Research Council, Anadarko, Canadian Fertilizers, The CO_2 Hub, Enbridge, EnCana, Husky, Paramount Resources, Penn West, Praxair, Shell Canada, Suncor, and the University of Calgary.

In addition, co-chairs are provided by Alberta Energy, Devon Canada, and Natural Resources Canada.

Contact

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The PTAC web site is www.ptac.org

Org 1.4: (Federal) Interdepartmental CCS Coordinating Committee

What is it? The Interdepartmental CCS Coordinating Committee brings together middle managers from all federal government departments that have responsibilities for CCS.

Role played in Canadian CCS The committee coordinates federal action, from research to industrial policy to international negotiations.

Description This committee was formed in response to the growing activities surrounding CCS in Canada and internationally. In particular, it helps to coordinate the federal response, on behalf of Canadians, to the role Canada plays in international negotiations on the reduction of greenhouse gases.

Representatives come from the departments of Natural Resources, Environment, Finance, Industry, and Foreign Affairs and International Trade, and from the Privy Council Office.

The Committee meets several times annually, particularly for planning the response to major events such as the recent COP/MOP meetings in Montreal during November and December 2005.

The Chair and Secretariat are provided by the Office of Energy R&D, Natural Resources Canada.

Contact

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Org 1.5: Ad Hoc Committee on CCS Public Education and Outreach

What is it? In the Ad Hoc Committee on CCS Public Education and Outreach the federal government (Natural Resources Canada), a province (Alberta) and an ENGO (Pembina Institute) promote public communications and outreach activities.

Role played in Canadian CCS Coordination of national initiatives regarding public education and outreach.

Description To date, the committee has supported two scoping studies to develop a path forward on public education and outreach:

- Towards a Strategy for Stakeholder Engagement on Geological Carbon Storage [Proj 16.1]
- Steps Toward a Strategic Plan for Citizen Involvement for Carbon Capture and Storage [Proj 16.3]

The committee has also supported a study titled "Public Attitudes Toward Geological Disposal of Carbon Dioxide in Canada" [Proj 16.5] and held preliminary discussions on a domestic strategy for public education and outreach.

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Org 1.6: Integrated Carbon Dioxide Network (ICO_2N)

What is it? The Integrated Carbon Dioxide Network is a group of private companies working jointly to establish a CO_2 system and infrastructure that allows for CO_2 capture, transportation, and storage.

Role played in Canadian CCS ICO_2N wants to establish a system that would enable CO_2 to be moved between sources and sinks.

Description The project is described as national in scope. It is setting out to design and create infrastructure that will serve long-term needs and not just build a pipeline linking current sources with near-term EOR applications. The project will help to establish the partnerships, tariffs, policy, incentives, and regulations required for success. The goal is to be sequestering 20 Mt CO_2 per year by 2020.

Participants to date include:

- Tier 1: Suncor Energy, Air Products Canada, Husky Energy, Nexen, and Shell Canada.
- Tier 2: Canadian Natural Resources, Agrium, ConocoPhillips Canada, Syncrude Canada, TransAlta, and Imperial Oil.

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2. COORDINATION AND PLANNING—INTERNATIONAL

Org 2.1: Carbon Sequestration Leadership Forum

What is it? The Carbon Sequestration Leadership Forum (CSLF) is composed of 21 countries that are major energy producers and users. The group encourages improvement in CCS technologies through coordinated policy development and R&D with international partners and private industry.

Role played in Canadian CCS Canada has been participating in the CSLF from its beginning, with the aim of sharing access to CCS information and of participating in projects outside Canada when possible.

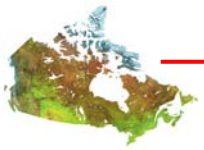
Description The CSLF was initiated by the U.S. Department of Energy in 2003. The group is open to developed countries regardless of whether they ratified the Kyoto protocol, and to developing countries. Notably, China, India, Brazil, and Saudi Arabia are members.

The activities of the CSLF are guided by a Policy Group, which sets the overall framework and policies, and by a Technical Group, which reviews the progress of collaborative projects. "Projects" is broadly defined to include planning, R&D, demonstrations, public outreach, economics and markets, and regulatory issues. The CSLF has recognized 17 projects, of which 4 are Canadian:

- Enhanced coalbed methane recovery, an existing project located at the Alberta Research Council [Proj 12.6]
- Oxyfuel combustion for CO_2 capture, an existing project located at the CANMET Energy Technology Centre–Ottawa [Proj 6.4, 6.5, 6.6, 6.7, 6.8, 6.9]
- CO_2 capture with chemical solvents, located at the International Test Centre, Regina [Proj 4.2]
- IEA GHG Weyburn–Midale CO_2 monitoring and storage project–final phase [Proj 17.3]

Notably, the U.S. Department of Energy has stated that it will use the CSLF to invite other countries to participate in FutureGen [Org 7.3], a 10-year $1 billion zero emission coal-to-electricity demonstration.

The most recent meetings of the Policy and Technical groups were held in Germany in September 2005. The next meetings will be held in India in April 2006.



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The web site for the Forum is www.cslforum.org

Org 2.2: International Energy Agency, Fossil Fuels Working Party

What is it? The Fossil Fuels Working Party (FFWP) is the IEA's permanent committee charged with advancing fossil-fuel energy technologies.

Role played in Canadian CCS CCS technologies are included in the mandate of the FFWP. Canada is a full and active member of the working party.

Description The working party, with representation from most of the IEA member countries, undertakes studies and organizes workshops that assist members with technology policy development. For convenience, the IEA (and therefore the working party) uses legal Implementing Agreements to formalize collective work by members interested in particular areas.

Several initiatives, each falling under a separate Implementing Agreement, are undertaking at least some CCS work.

The most significant is the IEA Greenhouse Gas R&D Programme (IEA GHG). This very active organization, located in the United Kingdom, is described in a separate entry in this compendium [Org 2.3].

Another is the Zero Emissions Technologies Initiative (for fossil fuels). Phase I was implemented in 2002–2004 and laid the groundwork for public outreach on the importance of ZETs—for collaboration, for commitments to develop and deploy ZETs, for cooperation with non-member countries, and for the safety and security of fossil-fuel systems. Phase II is in effect from 2005–2007; it is designed to improve public and political awareness and to advance the infrastructure to succeed (technology development, human and institutional capacity, financing enabled, and legal issues addressed). CCS is an integral part of ZETs.

A third activity is the Climate Technology Initiative (CTI), which consists of committees of IEA country representatives. These committees act to facilitate technology transfer to developing and transition countries. The tools used include technology needs assessments, seminars and symposia, implementation activities, training courses, and information dissemination. The CTI includes CCS in its mandate.

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Org 2.3: International Energy Agency, Greenhouse Gas R&D Programme

What is it? The IEA Greenhouse Gas R&D Programme (IEA GHG) is an international program, with offices and staff in the United Kingdom, that promotes international research projects, issues reports, and organizes meetings and conferences, all with the aim of reducing GHG emissions.

Role played in Canadian CCS Canada is a full member of the Programme, which is a window into international progress and events, especially with respect to technology. The Programme supports (among other things) international participation in the monitoring of the Weyburn Phase I and Weyburn-Midale Final Phase CO_2 EOR projects [Proj 14.3, 17.3].

Description The Programme operates under an IEA Implementing Agreement. Its offices, with a staff of about ten, is near Cheltenham, Gloucestershire, United Kingdom. Nearly 20 countries are members, including Canada, the United States, Japan, and the European Union. More than 10 corporations sponsor the Programme's work.

Nearly all the Programme's activities involve CCS, with the aims of

- evaluating technologies that reduce GHGs.
- disseminating results of the evaluation studies
- facilitating research, development, and demonstration.

Activities to date have covered all the main anthropogenic greenhouse gases—CO_2, CH_4, N_2O, and high GWP gases—although the primary focus is on CCS.

Projects sponsored by the Programme include monitoring the fate of CO_2 at two large sequestration sites: the commercial CO_2 EOR Weyburn–Midale operations in southeast Saskatchewan, and the CO_2 injection and storage demonstration in an undersea deep saline aquifer in the Sleipner West Field off the coast of Norway.

Canadians are involved in several of the Programme's activities. Information on the Programme's work and Canadian participation is available through the CANMET Energy Technology Centre–Ottawa.

The Programme is the guardian of the very large, biennial series of conferences: Greenhouse Gas Control Technologies. The most recent was GHGT-7 in Vancouver (2004); the next will be GHGT-8 in Trondheim, Norway, in June 2006.

The Programme is now covered by an Implementing Agreement, under the IEA Fossil Fuels Working Party [Org 2.2].

Contact

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The web site for the Programme is www.ieagreen.org.uk.

Org 2.4: Interstate Oil and Gas Compact Commission

What is it? The Interstate Oil and Gas Compact Commission (IOGCC) is an organization at the U.S. state governor level that represents the oil and gas producing states.

Role played in Canadian CCS some of the IOGCC work on CCS has considered the situation in Canada. A major report on CCS refers to Canada and could be of value for Canada's regulators.

Description The IOGCC has formed a Geological CO_2 Sequestration Task Force. The Task Force, funded by the U.S. Department of Energy and the National Energy Technology Laboratory, comprises representatives from IOGCC member states and international affiliate (Canadian) provinces, and state oil and natural gas agencies (among others).

The IOGCC produced a major report, released early in 2005, on the technical, policy, and regulatory issues related to CCS. In particular, the report contains an assessment of the current regulatory framework applicable to carbon capture and geological storage, and recommended regulatory guidelines and guidance documents for the states and provinces. The report can be found on the IOGCC web site.

Contact The IOGCC web site is http://www.iogcc.oklaosf.state.ok.us/.

Org 2.5: United Nations Framework Convention on Climate Change

What is it? The UN Framework Convention on Climate Change (UNFCCC) is an agreement, signed by nearly 200 countries, that sets an overall framework for world efforts to tackle the challenge posed by climate change. Under the Convention, GHG emission reduction targets, and the rules thereof, are established.

Role played in Canadian CCS Canada will be subject to UNFCCC rules (or those to which it signs on) with respect to CCS. Canada also plays a role in setting those rules.

Description Under the UNFCCC, governments

- share information on GHG emissions, policies, and practices.
- launch national strategies for addressing GHG emissions, including the provision of support to developing countries.
- cooperate in preparing for adaptation to the impacts of climate change.

Technical advice to the UNFCCC is received from the Intergovernmental Panel on Climate Change [Org 2.6].

The most recent major meeting of the UNFCCC (COP 11 and MOP 1, December 2005, in Montreal) was followed by a press release outlining the next steps in general terms (UNFCCC press release [10 December 2005] *United Nations Climate Change Conference agrees on future critical steps to tackle climate change*). Notably, CCS was the only technology mentioned in the press release. Reference was also made to the recent IPCC *Special Report on Carbon Dioxide Capture and Storage* [Doc 1.5].

CCS has already entered the lists of cooperative projects. The Clean Development Mechanism (CDM), which promotes GHG reductions in developing countries, has a mandate that includes CCS.

Many Canadians are involved in the activities of the UNFCCC. The two contacts below have responsibilities for UNFCCC activities that include CCS.

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The UNFCCC web site is www.unfccc.int.

Org 2.6: Intergovernmental Panel on Climate Change

What is it? The Intergovernmental Panel on Climate Change (IPCC) is the world's largest network of scientists examining climate change.

Role played in Canadian CCS The IPCC recently singled out CCS for special consideration, producing a major publication, *Special Report on Carbon Dioxide Capture and Storage* [Doc 1.5]. Canadians participated in preparing that document.

Description The IPCC was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). It is open to all members of the UN and WMO. The role of the IPCC, as described on its web site, is "to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation." The IPCC does not itself carry out research, nor does it monitor climate-related data or other relevant parameters. It bases its assessment mainly on peer-reviewed and published scientific and technical literature. It does not recommend policy—it is policy relevant, not policy prescriptive.

It is the growing importance of CCS that led the IPCC to request Working Group III (one of the IPCC's three major divisions) to gather and analyze information, resulting in the production of an exhaustive report on the subject. In the course of this work, Canada played host to a workshop (Regina, November 2002) and to the the final Working Group III Approval Session (Montreal, September 2005). The final product is the landmark publication *Special Report on Carbon Dioxide Capture and Storage* [Doc 1.5], which is an authoritative source on technology, environment, and other issues for the Canadian CO_2 community.

Nominally, individuals and not governments contribute to the IPCC's work, although governments can help by coordinating the response. Canadians who helped to write the *CCS Special Report* include David Keith, University of Calgary ("Summary for Policy Makers"); Brad de Young, Memorial University ("Ocean Storage"); and Stefan Bachu, Alberta Geological Survey ("Properties of CO_2 and Carbon-Based Fuels").

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The IPCC web site is www.ipcc.ch.

Org 2.7: Asia–Pacific Economic Cooperation, Expert Group on Clean Fossil Energy

What is it? The Expert Group on Clean Fossil Energy (EGCFE), with membership from interested APEC members, promotes the use of clean fossil energy technologies, especially among developing countries.

Role played in Canadian CCS Canada is represented on the EGCFE, giving Canadians exposure to other CCS activities and giving Canadian companies an opportunity to participate in projects in the APEC countries.

Description The EGCFE is one of five expert groups reporting to the Energy Working Group (EWG).

To accomplish its mission, the EGCFE first identifies a potential project, referring it to senior bodies for approval and funds. Following funding approval, the country that initiated the project normally becomes the Project Overseer, who then leads the request for proposals, award of contract, contract supervision, and acceptance of the product.

With respect to CCS, Canada initiated in 2001 a CCS program that has so far incorporated three phases (projects).

Phase I (completed) was a report by an Australian company (Carbon Technologies Pty Ltd.), on CCS opportunities in Southeast Asia. This report is available on the EWG web site.

Phase II saw a contract awarded to two Canadian organizations (the Delphi Group [Org 8.12] and the Alberta Research Council [Org 4.2]) who produced training manuals and held a workshop in South Korea in 2005. Reports are available on the EWG web site.

In Phase III another contract was awarded to a consortium consisting of the Canadian companies from phase II and the Australian organization from phase I to tailor and update the training manuals, hold workshops in 2006 in China and Mexico, and undertake a preliminary assessment of the geological potential for CO_2 storage in Mexico.

More information on these phases is available [Proj 16.2].

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Org 2.8: The Plains CO_2 Reduction Partnership (United States and Canada)

What is it? The Plains CO_2 Reduction Partnership (PCOR) is a collaboration of private and public sector organizations in the Great Plains states and provinces, whose goal is to capture and store carbon. The DoE has defined "Plains" to include seven states and three provinces (Alberta, Saskatchewan, and Manitoba). This is a U.S. initiative.

Role played in Canadian CCS Canadian partners receive access to developments in CCS and to "partners only" data and information.

Description The PCOR Partnership is one of seven regional partnerships funded by the U.S. Department of Energy's National Energy Technology Laboratory Regional Carbon Sequestration Partnership Program. It is coordinated by the Energy and Environmental Research Center (EERC) at the University of North Dakota.

This collaborative effort of more than 40 public- and private-sector stakeholders works toward a better understanding of the technical and economic feasibility of capturing and storing ("sequestering") anthropogenic CO_2 emissions from stationary sources in the Great Plains and adjacent areas of North America.

The Partnership's scope includes regional CO_2 sources, sequestration options, regulatory assessments, environmental issue assessments, and project modelling.

Examples of specific PCOR products, available to partners, are interactive geographic information system (GIS) databases featuring CO_2 sources, sinks, and infrastructure, and regulatory and environmental areas of interest.

The Alberta Energy and Utilities Board is a member of the PCOR Partnership.

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3. RESEARCH—FEDERAL GOVERNMENT

Org 3.1: Natural Resources Canada, CANMET Energy Technology Centre–Ottawa

What is it? CANMET Energy Technology Centre–Ottawa (CETC-O) is a research arm of Natural Resources Canada. It conducts and funds research, technology development, and implementation in energy supply and utilization.

Role played in Canadian CCS CETC-O uses its world-class facilities and expertise (for example, in combustion and catalysis) to investigate CO_2 capture and related issues. It also funds CO_2 research, development, and demonstration and provides coordination (national and international) for many Canadian activities.

Description CETC-O, with a staff of about 250, conducts inhouse R&D using its extensive research and pilot facilities in many aspects of energy technology (clean sources, renewables, and efficient end use) with a strong focus on environmental issues, notably climate change. It also manages a number of S&T funding programs for the federal government in these same areas (approximately $25 million annually) including one specifically targeted at CCS. CETC-O has established wide-ranging partnerships with universities, other government agencies, and especially industry. It is a sister organization to CETC-Devon in Devon, Alberta [Org 3.2].

One of CETC-O's strengths is its extensive combustion program, which for CCS includes oxyfuel combustion [Proj 6.4, 6.5, 6.6, 6.7, 6.8, 6.9], gasification [Proj 5.2, 5.3, 5.4], plasma cleaning [Proj 4.13], and chemical looping combustion [Proj 8.5, 8.6]. CETC-O also has two CCS projects related to fuel cells [Proj 8.9, 8.10].

CETC-O representatives are active in several Canadian CCS organizations, the most prominent being the Canadian CO_2 Capture and Storage Technology Network [Org 1.1]. CETC-O also coordinated the development of the Technology Roadmaps [Doc 1.1, 1.2]

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The CETC-O web site is www.nrcan.gc.ca/es/etb/cetc/cetc01/htmldocs/home_e.htm.

Org 3.2: Natural Resources Canada, CANMET Energy Technology Centre–Devon [Alberta]

What is it? The CANMET Energy Technology Centre–Devon (CETC-Devon) is a research arm of Natural Resources Canada. CETC-Devon conducts research, technology development, and implementation in hydrocarbon energy supply and related environmental technologies, with an emphasis on oil sands and heavy oil.

Role played in Canadian CCS CETC-Devon looks at the means of CCS associated with oil sands and heavy oil production, notably fixing CO_2 in oil sands tailings.

Description CETC-Devon, located at Devon, southwest of Edmonton, has a staff of about 110. There are two principal research groups, Advanced Separations Technology (AST) and the National Centre for Upgrading Technology (NCUT), the latter being a joint venture with the Alberta Research Council [Org 4.2]. AST and NCUT both have laboratory-scale, pilot-plant, and field capabilities for scale-up and demonstration of a wide range of technologies related to bitumen and heavy oil extraction and upgrading.

The organization's principal area of CCS interest is sequestration of CO_2 in oil sands tailing streams. Two projects are under way: one on the fundamentals of the chemistry [Proj 15.8], and the other on reducing CH_4 release [Proj 15.9].

The project integrator (Carolyn Preston) for the final phase of the Weyburn–Midale CO_2 monitoring and storage project [Proj 17.3] is located in the same research centre as CETC-Devon.

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The CETC-Devon web site is www.nrcan.gc.ca/es/etb/cwrc

Org 3.3: Geological Survey of Canada

What is it? The Geological Survey of Canada (GSC) is the federal government's premier agency for geoscientific information and research.

Role played in Canadian CCS The GSC maintains, and continues to develop, records of the geological structures in Canada into which CO_2 can be injected for long-term storage or permanent disposal.

Description The GSC brings together geologists, geophysicists, and scientists in other disciplines from all parts of Canada, but particularly from the Western Sedimentary Basin (the Prairie provinces) and from the coal-producing areas of the Nova Scotia.

The GSC's history of providing a high-quality base of geological information as for Canada's oil and gas and mining industries applies equally well in identifying the potential for CO_2 storage. Some current projects are these:

- CO_2 storage capacity of deep coal seams in the vicinity of large CO_2 point sources in central Alberta and Nova Scotia [Proj 2.5]
- Geologic sequestration of CO_2 and simultaneous CO_2 sequestration/CH_4 production from natural gas hydrate reservoirs [Proj 10.5]
- Degree of coal swelling and loss of permeability associated with sequestration of CO_2, H_2S, and flue gas–selecting optimum coals for sequestration (joint with the University of British Columbia) [Proj 12.7]
- Enhanced coalbed methane recovery for zero GHG emissions (Alberta Research Council, GSC, and many others) [Proj 12.8]
- Fixation of GHGs in mine residues (joint with the University of British Columbia) [Proj 15.1]
- *In situ* monitoring methods for geological sequestration [Proj 14.1]

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Org 3.4: National Research Council of Canada, Institute for Chemical Processing and Environmental Technology

What is it? The National Research Council (NRC) is the government of Canada's premier science and technology research organization. Within NRC, the mandate of the Institute for Chemical Processing and Environmental Technology (ICPET) includes support of Canada's energy-intensive industries.

Role played in Canadian CCS ICPET conducts research on chemical systems, giving it the capacity to undertake some projects on CO_2 capture.

Description ICPET has chemical science and engineering capabilities directed toward research, development, and technology commercialization. ICPET has become engaged in several projects related to CCS.

One project covers electric power production from circulating fluidized bed combustor boilers with CO_2 capture (joint with others) [Proj 6.9]. Another studies CO_2 separation from flue gases using polymer–zeolite composites [Proj 7.4].

Other enquiries into novel technologies include zero emissions direct fuel cells (joint with others) [Proj 8.10] and hydrate technology for gas separation (joint with others) [Proj 8.13]. Another hydrate project involves natural gas reservoirs (joint with others) [Proj 10.5].

Contact

See individual project pages.

Org 3.5: Natural Resources Canada, CANMET Mining and Mineral Sciences Laboratories

What is it? The CANMET Mining and Mineral Sciences Laboratories (MMSL) are federal government research laboratories within the CANMET Mineral Technology Branch of Natural Resources Canada. CANMET-MMSL provides research and scientific advice to the mining and minerals industries, and to provincial/territorial and federal government departments involved in promoting or regulating these industries.

Role played in Canadian CCS CANMET-MMSL will conduct research to mitigate CO_2 emissions.

Description There is one project by CANMET-MMSL described in this compendium. It examines the use of microalgae to absorb large quantities of CO_2 [Proj 15.11].

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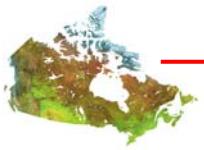

4. RESEARCH—PROVINCIAL GOVERNMENTS

Org 4.1: Alberta Energy

What is it? Alberta Energy (Alberta's Department of Energy) manages the development of the province's energy and mineral resources.

Role played in Canadian CCS CCS support is given to companies collecting information, developing technologies, or demonstrating the use of CO_2 in the development of the province's oil and gas resources.

Description Alberta Energy hosts the management of the province's Innovative Energy Technologies Program. One of these is the CO_2 Projects Royalty Credit Program, which currently provides tax relief to test pilot projects using CO_2 enhanced recovery [Org 11.13].

Another organization that is separate from the Department of Energy, but that reports to the Minister of Energy, also supports CCS. This is the Alberta Energy and Utilities Board, which heads a large organization that includes the Alberta Geological Survey. The Survey currently conducts or supports a number of CCS projects [Org 4.3].

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The Alberta Energy web site is www.energy.gov.ab.ca.

Org 4.2: Alberta Research Council, Carbon and Energy Management Unit

What is it? The Carbon and Energy Management Unit of the Alberta Research Council (ARC) consists of about 20 scientists (and associated staff) working on programs of clean energy, geological storage, and unconventional natural gas.

Role played in Canadian CCS The Unit's geological storage program focuses on acid-gas injection, CO_2 EOR, CO_2 enhanced coalbed methane recovery (ECBM), and monitoring technologies.

Description The CCS Group, located primarily at the ARC facilities in Edmonton, conducts both field and laboratory work and carries out projects, often jointly with Canadian and international partners.

The Group's CCS projects focus on CO_2 enhanced oil and gas production leading to CO_2 storage. A joint project with the Alberta Geological Survey [Proj 10.1] has the goal of implementing a CO_2 monitoring program to assess the fate of acid gas and of testing various techniques at a field site as an analog for CO_2 storage. Another aims to develop an integrated economic model to evaluate CCS options [Proj 17.2]. A third is studying how to optimize CO_2 storage in oil reservoirs [Proj 11.10].

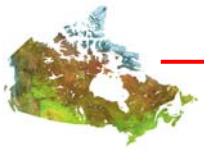
The Unit participated in the Weyburn EOR CO_2 Monitoring project [Proj 14.3] by conducting geochemical sampling and reservoir simulations. The Group is also leading a CO_2 monitoring program at a CO_2 EOR pilot site in Alberta [Proj. 14.4, 14.5]. A project to develop protocols for CO_2 geological storage is being initiated [Proj 13.5].

The ARC-led Alberta ECBM project [Proj 12.6] has led to a multi-well pilot championed by Suncor at a site in Alberta [Proj 12.5]. The Group will piggyback on the project to implement a monitoring program. A joint industry project to enhance permeability (storage in tight reservoirs) is being initiated. International projects include an enhanced coalbed CH_4 and CO_2 storage pilot in China, jointly with several others [Proj 12.4].

The Group, jointly with the Delphi Group of Ottawa, has an APEC project in capacity building for CCS in APEC economies [Proj 16.2]. A set of training modules has been developed and workshops in China and Mexico are being planned.

Jointly with the University of Waterloo, ARC is to develop hollow-fibre technology as a way of separating CO_2 from gas streams that is more effective than amine solvents [Proj 7.1].

The Group's staff members are active in the national and international CCS community—for example, by developing conferences and roadmaps and also by contributing to the 2005 IPCC *Special Report on Carbon Dioxide Capture and Storage* [Org 2.6 and Doc 1.5].



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The ARC web site is www.arc.ab.ca.

Org 4.3: Alberta Geological Survey, Acid Gas and CO_2 Storage Section, Alberta Energy Utilities Board

What is it? The Alberta Geological Survey (AGS) is part of the Alberta Energy and Utilities Board (AEUB). It provides geoscience information and expertise for the province. The AGS has an Acid Gas and CO_2 Storage Section, a group of about 10 professionals headquartered in Edmonton.

Role played in Canadian CCS The Acid Gas and CO_2 Storage Section is the largest government unit in Canada dedicated exclusively to CO_2 (and acid-gas) geological sequestration. In addition to carrying out direct and significant work on CO_2 sequestration in Alberta, staff members are active beyond the province.

Description The formal objectives of the Section's program are to evaluate Alberta's potential for geological sequestration of greenhouse and acid gases (CO_2, H_2S) and to identify sites and opportunities for early, large-scale implementation. The components of the program are the potential means of sequestration, identification of major CO_2 sources and basin suitability, and acid-gas injection.

Current projects include studies into the suitability of Canada's sedimentary basins for CO_2 sequestration [Proj 2.1], with a particular emphasis on Western Canada [Proj 2.2], and the CO_2 storage capacity in Alberta's coalbeds [Proj 2.4] and oil and gas reservoirs in Alberta and northeastern British Columbia [Proj 2.3]. Other projects include acid-gas re-injection into Alberta and British Columbia (joint with the Alberta Research Council) [Proj 10.1] and reservoir performance in Alberta [Proj 10.2]. The Section also participates in monitoring two of Alberta's CO_2 injection pilots [Org 8.5].

The Section's work beyond the Alberta borders (in addition to those mentioned above) includes being a being a long-standing and major player in the Canadian CO_2 Capture and Storage Technology Network [Org 1.1]. Internationally, staff were active participants in the new IPCC *Special Report on Carbon Dioxide Capture and Storage* [Org 2.6, Doc 1.5], the Carbon Sequestration Leadership Forum [Org 2.1], and building CCS capacity in APEC countries [Org 2.7].

In addition, the AEUB is a member of the PCOR Partnership [Org 2.8], one of seven regional partnerships organized by the U.S. government. AGS staff are actively involved in one of their pilot demonstration projects in northern Alberta.

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Org 4.4: Alberta Energy Research Institute

What is it? The Alberta Energy Research Institute (AERI) is a component of the Alberta government's Ministry of Innovation and Science. It provides strategic direction to the government and invests in research and technology in support of the province's energy industry.

Role played in Canadian CCS AERI supports several CCS projects.

Description The Ministry of Innovation and Science promotes science, research, and development by providing strategic leadership, by managing and funding strategic investments, and by coordinating government initiatives for science and research in the province. AERI, which has offices in Calgary and Edmonton, is responsible to the Ministry through the Alberta Science and Research Authority (ASRA), an independent board of members from Alberta's academic, business, and research communities.

AERI provides analysis and funding for projects done by others. The CCS projects it supports include estimates of the CO_2 storage potential in the Western Sedimentary Basin [Proj 2.3], technologies of CO_2 flooding [Proj 11.6], enhanced coalbed CH_4 [Proj 12.3], monitoring of CO_2 in commercial or near-commercial EOR [Proj 14.4, 14.5] and a look at the highly innovative technologies of storing CO_2 in hydrate form [Proj 15.4] and of sequestering CO_2 during bitumen recovery [Proj 15.10].

AERI continues to look for opportunities to advance emissions reduction through CCS.

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The AERI web site is www.aeri.ab.ca.

Org 4.5: Saskatchewan Research Council, Energy Division

What is it? The Energy Division of the Saskatchewan Research Council (SRC) is the largest research organization in the province.

Role played in Canadian CCS The Division's research program includes studies on CO_2 flooding and sequestration.

Description The SRC, with laboratories in Regina and Saskatoon, is a corporation of the provincial government, responsible to the minister of Industry and Resources. It has a staff of 225 and annual revenues of about $26 million. Energy is one of SRC's six divisions.

The Energy Division works with clients and partners on the recovery and processing of non-renewable sources of energy, such as heavy oil and oil sands, and on renewable sources. It works closely with the Petroleum Technology Research Centre [Org 4.6].

SRC and its Energy Division have expertise in determining the conditions and potential for GHG sequestration. Having provided key data for the development of the CO_2 flood project in Weyburn reservoir in southeast Saskatchewan, SRC is now involved in the IEA-sponsored Weyburn Phase I and Weyburn-Midale Final Phase CO_2 Storage and Monitoring Projects [Org 7.4, Proj 14.3, Proj 17.3].

With the Petroleum Technology Research Centre [Org 4.6], SRC is developing, adapting, and applying oil recovery processes to suit a range of reservoir conditions, oil types, and operating constraints. These methods include miscible or near-miscible CO_2 injection for light oil and CO_2 and flue-gas huff'n'puff for heavy oil [Proj 11.8].

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The SRC web site is www.src.sk.ca.

Org 4.6: [Saskatchewan] Petroleum Technology Research Centre

What is it? The Petroleum Technology Research Centre (PTRC) is a nonprofit research and development organization with offices and laboratories in Regina.

Role played in Canadian CCS The Centre is a leader in EOR and geological storage of CO_2.

Description Located in Regina's Research Park, adjacent to the University of Regina campus, PTRC was founded by the University of Regina, the Saskatchewan Research Council, Saskatchewan Industry and Resources, and Natural Resources Canada with support from the western Canadian oil and gas industry.

PTRC sees itself as a conduit for federal, provincial, and industry funding for industry-oriented petroleum research. It is designed to bring the conceptual research of the University of Regina and Saskatchewan Research Council into the field. PTRC develops and tests research that is readily applicable to industrial partners in western Canada and beyond.

PTRC's central building provides offices and laboratories that accommodate PTRC staff, faculty and graduate students of the University of Regina's Petroleum Systems Engineering program, and researchers with the Saskatchewan Research Council's Energy Division [Org 4.5].

PTRC coordinated the IEA GHG Weyburn CO_2 Monitoring and Storage Project [Proj 14.3, 17.3]. It continues to work with the Saskatchewan Research Council to see how CO_2 EOR practices can be improved and extended to heavier oils [Proj 11.8].

For the future, PTRC plans to study the safety and suitability of saline aquifers for CO_2 geological storage.

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The PTRC web site is www.ptrc.ca.

Org 4.7: British Columbia Ministry of Energy, Mines and Petroleum Resources, Resource Development and Geoscience Branch

What is it? Resource Development and Geoscience is a Branch within the B.C. Ministry of Energy, Mines and Petroleum Resources.

Role played in Canadian CCS The B.C. government's support of CCS is concentrated in this Branch.

Description The Branch has supported and continues to support varied studies into CCS in the B.C. context, including the unique technology of carbonization of CO_2.

Past studies have investigated the potential of CO_2 sequestration in British Columbia's coal seams.

In a unique contribution to the Canadian search for locations to dispose of CO_2, the Branch has pursued the potential (and science) of carbonization of CO_2 and of suitable B.C. minerals for the practice. British Columbia's ultramafic rocks have been studied over the years as possible hosts of base metals, precious metals, and gemstones. CO_2-related studies draw relevant information from that research and utilize the database originally designed to evaluate mineral potential for the province.

Currently, the Branch is studying the overall potential of CCS in the province and, in particular, the mineral carbonization of CO_2 [Proj 1.1]. Two studies on the potential of CO_2 sequestration in B.C. coal, oil, and gas fields are also under way [Proj 2.6, 2.7].

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5. RESEARCH—UNIVERSITIES

Org 5.1: Canadian Universities (Overview)

What is it? Many Canadian universities are creating leading-edge S&T for Canada's resource industries and for protection of the environment.

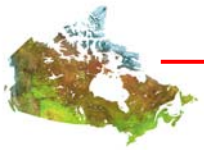
Role played in Canadian CCS Several universities have groups dedicated in whole or in part to CCS. A number of independent research projects are also underway outside those groups. Overall, topics range from basic science to technology development to behavioral studies.

Description

- University of Calgary
  CCS is contained in the mandate of the new Institute of Sustainable Energy, Environment and Economy [Org 5.2].
- University of Regina
  Two research centres are the CO_2 Capture Research Group [Org 5.3] and the International Test Centre for CO_2 Capture [Org 5.4]. Plans are in place for a new Centre for Studies in Energy and Environment. In addition, there are two geological storage projects at the University [Proj 11.9, 13.4]. The Petroleum Technology Research Centre [Org 4.6], although closely allied to the University, is classified under "Research—Provincial Governments."
- University of Waterloo
  The new (2003) Green Energy Research Institute [Org 5.5] brings together CCS research at the university.
- University of British Columbia
  Three groups, the department of Earth and Ocean Sciences, the department of Chemical and Biological Engineering, and the Institute for Resources, Environment and Sustainability are described on one page [Org 5.6].
- Simon Fraser University
  The Energy and Materials Research Group [Org 5.7] is studying economics and policy.
- University of Alberta
  The university hosts the School of Mining and Petroleum Resources [Org 5.8].

Other Canadian universities are also hosting CCS projects:

- University du Québec à Montréal
  Solid CO_2 sorbents [Proj 8.1]; small-scale capture [Proj 4.1].
- University of Ottawa
  New methods of CO_2 scrubbing [Proj 8.2, 8.3], CO_2 reactivity [Proj 8.11], and CO_2 and hollow-fibre membranes [Proj 7.2].
- University of Saskatchewan
  Methane reforming [Proj 8.8], and regional-scale mapping of CO_2 storage sites [Proj 10.3].
- McGill University



CO_2 in concrete (joint with others) [Proj 15.2], and CH_4 and CO_2 hydrates [Proj 15.3].

- University of Victoria
  CO_2 sequestration in British Columbia, joint with the B.C. Ministry of Energy, Mines and Petroleum Resources [Proj 1.1].
- Carleton University
  Advanced power cycles using oxyfuel combustion (joint with the University of Waterloo) [Proj 6.1], and Brayton-cycle-based zero emission power plant [Proj 6.2].
- Dalhousie University
  Nova Scotia CO_2 storage [Proj 10.4].
- Université Laval
  The use of asbestos tailings to fix and store CO_2 [Proj 15.7]
- University of Western Ontario
  The fixation of carbon in mine tailings, a joint project with the University of British Columbia [Proj 15.6].

Contact See the individual organization and project pages.

Org 5.2: University of Calgary, Institute of Sustainable Energy, Environment and Economy

What is it? The Institute of Sustainable Energy, Environment and Economy (ISEEE) is a new (October 2003) institute at the University of Calgary. It develops research, education, and innovation programs in the interconnected areas of sustainable energy, the environment, and the economy, drawing upon the faculty and facilities of the university and its partners and collaborators.

Role played in Canadian CCS The ISEEE consists of four main groups, all of which include carbon management (including CO_2 emissions reduction) in their mandate. Notable groups are the Carbon Management Group (CMG), which is dedicated to CCS, and the Advanced Recovery and Upgrading Group (ARUG), which looks at utilizing CO_2 for advanced hydrocarbon recovery in conjunction with sequestration in hydrocarbon reservoirs.

Description ISEEE ensures that its work harmonizes with Alberta's energy and environmental strategies. The Institute is aligned with a Memorandum of Understanding entered into by the Alberta Energy Research Institute and the universities of Alberta, Calgary, and Lethbridge. It is also aligned with the federal innovation agenda.

The university's research on CCS includes these projects:

- EOR using CO_2 injection [Proj 11.6, 11.7]
- Enhanced coalbed methane recovery using CO_2 injection [Proj 12.9, 12.10]
- Risk management of CO_2 storage systems (joint with the University of Alberta) [Proj 13.7]
- Monitoring the fate of CO_2 EOR and sequestration in the Pembina Cardium oil reservoir (joint with industry—Penn West Petroleum and others) [Proj 14.4]
- Other routes for storage are CO_2 sequestration via gas hydrates [Proj 15.4] and CO_2 as a Vapex solvent [Proj 15.10]

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The ISEEE web site is www.iseee.ca.

Org 5.3: University of Regina, CO_2 Capture Research Group

What is it? The CO_2 Capture Research Group is a team of about 20 scientists and graduate students working at laboratories and in small pilot plant units.

Role played in Canadian CCS The Group, which has close ties to industry, pursues advanced CO_2 separation technologies.

Description Main areas of research are industrial gas processing and CO_2 removal from flue gases and other industrial gas streams. The Group's focus and location is designed to fit with Saskatchewan's hydrocarbon industry.

The Group emphasizes CO_2 capture through the development and optimization of amine solvents and related processes. Areas of research and some projects are these:

- High-efficiency gas-testing systems [Proj 3.5]
- Capture—with a heavy emphasis on amine solvents—is covered in topics as diverse as mass transfer, amine degradation, new solvent development, molecular design, and corrosion inhibitors [Proj 4.4–4.12]

The Research Group's program complements that of the University of Regina's International Test Centre for CO_2 Capture [Org 5.4].

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The CO_2 Capture Research Group web site is www.uregina.ca/engg/co2/co2res.htm.

Org 5.4: University of Regina, International Test Centre for CO_2 Capture

What is it? The International Test Centre (ITC) consists of a university-located CO_2 capture laboratory and a nearby pre-commercial demonstration facility.

Role played in Canadian CCS The ITC has analytic and research capability with capacity for technology demonstration of post-combustion CO_2 capture technologies, especially separation using amines.

Description The ITC is developing post-combustion capture technologies that can reduce the cost and energy penalty of CO_2 production.

The Centre relies on existing expertise at the University of Regina. Eight professors (researchers) are on staff, plus plant operators and others.

The has two capital components:

- A $3 million pilot plant installation at the University site for GHG capture technology development and screening.
- A $5 million pre-commercial technology demonstration plant at SaskPower's coal-fired Boundary Dam Power Station near Estevan, Saskatchewan.

The Centre also uses three university pilot plant units to test high-efficiency gas-treating systems; varying sizes of absorption and regeneration towers are used with a variety of high-performance packing. Other research components are used for solvent absorption capacity, for solvent stability and corrosion, and for gas and liquid diffusivity determination.

The ITC's program is planned in close cooperation with the University of Regina's CO_2 Capture Research Group [Org 5.3]. Also involved are the Universities of Waterloo, British Columbia, and Calgary.

The project description [Proj 4.2] lists the numerous funders of the Centre.

A smaller project, identified in this compendium, is a study into cost reduction of amine-based solvent CO_2 capture processes [Proj 4.3].

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The ITC web site is www.co2-research.ca.

Org 5.5: University of Waterloo, Green Energy Research Institute

What is it? The Green Energy Research Institute (GERI) is a new organization at the University of Waterloo that promotes collaboration among research projects at the university that contribute to environmentally friendly energy use.

Role played in Canadian CCS Several projects are targeted directly at CCS.

Description Currently, the Institute's staff occupy offices only. Within two years, GERI will move to a new building, complete with laboratory facilities, dedicated to green energy studies. Meanwhile, the Institute conducts paper studies (computer modelling and analysis) and, in its compilation of green energy activities, includes Waterloo scientists and research projects. For CCS, these projects include:

- optimization of CO_2 capture, transportation, and storage systems [Proj 1.2, 1.3].
- studies of capture technologies in various generation systems and capture configurations [Proj 3.1, 3.2, 3.3, 3.4].
- evaluation of technical and economic performance of advanced power cycles using oxyfuel combustion (joint with Carleton University) [Proj 6.1] and improvement of the efficiency of oxyfuel processes [Proj 6.3].
- study of combinations of membranes and pressure-swing absorption for separation of CO_2 [Proj 7.3].

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The GERI web site is www.geri.uwaterloo.ca.

Org 5.6: University of British Columbia, Three Organizations

What is it? Two major departments within the university conduct fundamental and applied research into areas of interest to British Columbia. An associated institute applies modelling and analysis of resources and environment for policy development.

Role played in Canadian CCS The organizations conduct pioneering studies into radical forms of geological sequestration of CO_2, separation of CO_2 from flue gases, and citizen involvement in CCS policy.

Description At the department of Earth and Ocean Sciences (EOS), Greg Dipple is leading fundamental research into CO_2 sequestration via mineral carbonation, a way of locking up CO_2 permanently (and using serpentine rocks, found in abundance in parts of B.C.) [Proj 15.1, 15.5, 15.6]. Marc Bustin is examining CO_2 sequestration in coalbeds and in organic-rich rocks [Proj 12.1, 12.8].

The department of Chemical and Biological Engineering (CBE) is studying the utilization of metal oxide as an oxygen carrier to separate flue gas streams in a combustion system [Proj 8.4].

The Institute for Resources, Environment and Sustainability (IRES) has studied citizen involvement for carbon capture and storage decisions in Canada [Proj 16.3].

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The Earth and Ocean Sciences web site is www.eos.ubc.ca.
The Chemical and Biological Engineering web site is www.chml.ubc.ca.
The Institute for Resources, Environment and Sustainability web site is www.ires.ubc.ca.

Org 5.7: Simon Fraser University, Energy and Materials Research Group

What is it? The Energy and Materials Research Group (EMRG) is a group of 20 faculty, research associates, and graduate students studying the flow of energy and materials in society.

Role played in Canadian CCS Some research projects are directed at the economics and public acceptability of CCS.

Description EMRG is a research unit coordinated by Mark Jaccard in the School of Resource and Environmental Management at Simon Fraser University. EMRG's staff apply information systems and analytical tools in the study of technologies, strategies, behaviour, and policies that lead to a more sustainable flow of energy and materials in society. A basis of EMRG's work is the Canadian Integrated Modelling System (CIMS) model, an integrated set of economic and energy models.

Target projects useful to both modelling and policy include these:

- Publication in fall 2005 of the report *Public Attitudes toward Geological Disposal of Carbon Dioxide in Canada* [Proj 16.5]
- Current investigation into the long-term technical and economic prospects for CCS in Canada, and evaluation of policy options to facilitate its development and implementation

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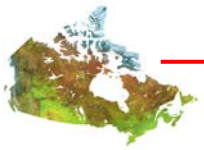
The Energy and Materials Research Group web site is www.emrg.sfu.ca.



Org 5.8: University of Alberta, School of Mining and Petroleum Resources

What is it? The School of Mining and Petroleum Resources is part of the university's faculty of Engineering.

Role played in Canadian CCS The School includes studies into geological storage of CO_2 in the oil and gas fields and coal deposits of the Western Sedimentary Basin.

Description Several CCS projects are under way:

- A study of groundwater and CO_2 migration in and around the Weyburn CO_2 EOR site (Daniel Khan) [Proj 11.1]
- Studies of enhanced CO_2 injection and methane recovery in coalbeds [Proj 12.2, 12.3]
- A study of the characteristics of caprocks and CO_2 disposal [Proj 13.1]
- A project on the modelling and monitoring of CO_2 storage sites (lead organization, joint with the Alberta Research Council) [Proj 13.5]
- A project examining the fate of CO_2 injected into the Pembina Cardium oil reservoir for EOR (joint with others) [Proj 14.4]

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6. RESEARCH—ENVIRONMENTAL NON-GOVERNMENTAL ORGANIZATIONS (ENGOs)

Org 6.1: The Pembina Institute

What it is? The Pembina Institute is an independent not-for-profit environmental policy research and education organization that focuses on energy and the environment.

Role played in Canadian CCS The Institute, having long held a watching brief on CCS, has now published a primer and a position paper.

Description The Institute has a multidisciplinary staff of approximately 40 and offices in Calgary, Drayton Valley (Alberta), Edmonton, Ottawa, and Vancouver. It operates major policy research and education programs in the areas of sustainable energy, climate change, environmental governance, ecological fiscal reform, sustainability indicators, and the environmental impacts of the energy industry.

With respect to CCS, the Institute published in November 2005 an overview of the subject and of its potential role in reducing GHG emissions (*Carbon Capture and Storage: A Canadian Primer*). The primer aims to provide information in a neutral manner; it does not reflect Pembina's policy position. The document is available on the Institute's web site.

The Institute's policy position on CCS is given in another document, which was published at the same time as the primer. This short document, *Carbon Capture and Storage: The Pembina Institute's Position,* outlines the role that CCS might play in combating climate change. In its conclusions, the Institute does not advocate allocating public money to CCS. However, if such allocations are made, the paper outlines the constraints under which the Institute believes such monies should be used.

The Pembina Institute is also a member of a small ad hoc committee in which it has joined with the federal government and the province of Alberta to promote CCS public communications and outreach activities [Org 1.5].

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The Pembina Institute web site is www.pembina.org.

7. RESEARCH—INTERNATIONAL

Org 7.1: International Energy Agency, Clean Coal Centre

What is it? The Clean Coal Centre is a long-established coordinating centre for advancing clean coal technologies. It now has an outreach mandate to work with developing countries.

Role played in Canadian CCS Provides access and contacts to advances around the world. Zero emissions technology (that is, eliminating CO_2 emissions) is studied, but the Centre's priority remains non-CO_2 emissions.

Description The Clean Coal Centre, located in London (United Kingdom), is a coordinating body for International Energy Agency (IEA) member countries. It has expanding connections to ship to transition economies (ex-Soviet bloc countries) and to developing countries such as Poland and China. It is supported by member subscriptions.

The Centre produces about 15 special reports annually, and works on the reduction of all coal-combustion emissions. CO_2 reduction has been approached through improvements in process efficiency. In recent years the Centre has added zero emissions to its mandate.

By contrast, the other relevant IEA organization, the GHG R&D Programme [Org 2.3], has CO_2, especially CSS, as its main focus by far. These IEA sister organizations have other differences:

Clean Coal Centre

- Coal, all emissions
- Short- and long-term issues
- All reports public
- Work done inhouse

GHG R&D Programme

- CCS, all fossil fuels
- Long-term issues
- Detailed reports to members only
- Work mostly contracted out

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The Clean Coal Centre web site is www.iea-coal.org.uk.

Org 7.2: CO_2 Capture Project

What is it? The CO_2 Capture Project (CCP2) is a joint project (actually, a number of projects) backed by a small number of the world's leading energy companies.

Role played in Canadian CCS The Project gives one of the major Canadian energy companies, Suncor, a place at the table on international projects selected by a group of well-funded companies of great experience.

Description The Project was formed as the 21st century began. The original Canadian participants were Suncor and Encana. The Project has now entered its second phase, with Suncor currently being the sole Canadian participant.

The primary objective of the CCP2 is to evaluate and develop new breakthrough technologies that reduce the costs of CO_2 separation, capture, and geologic storage from combustion sources such as turbines, heaters, and boilers. It will accomplish its objective by

- performing benchtop R&D (engineering studies, computer modelling, laboratory experiments) to prove the feasibility of advanced CO_2 separation and capture technologies. This work specifically targets post-combustion, pre-combustion decarbonization, and oxyfuel methods of CO_2 capture.
- developing guidelines for maximizing safe geological storage, for measuring and verifying stored volumes, and for assessing and mitigating storage risks.
- developing an economic model to establish lifecycle CO_2 separation, capture, and sequestration costs for current and best technologies to compare alternatives and to direct R&D toward the most promising technologies.
- examining the required policies and incentives to allow CCS to proceed on a large scale.

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The CO_2 Capture Project web site is www.co2captureproject.org.

Org 7.3: FutureGen (United States)

What is it? FutureGen is a U.S. Department of Energy initiative, with foreign participation invited, to build a prototype zero emissions fossil fuel plant.

Role played in Canadian CCS Canada is considering participation in FutureGen.

Description The FutureGen web site states that FutureGen is "an initiative to build the world's first integrated sequestration and H_2 production research power plant. The $1-billion dollar project is intended to create the world's first zero emissions fossil fuel plant. When operational, the prototype will be the cleanest fossil fuel fired power plant in the world."

The plant will employ coal gasification technology and be nominally sized to produce 275 MW equivalent gross electricity output.

Opportunities for international participation in FutureGen are available at various levels and can take several forms—for example,

- government-to-government cooperation, including participation on the Government Steering Committee through cost-sharing.
- membership of foreign coal producers and coal-fueled electric utilities in the Consortium.
- competitive opportunities for equipment vendors and engineering services to bid on FutureGen procurements.
- academic, scientific, and researcher participation in FutureGen testing.

Contact

Office of Fossil Energy
U.S. Department of Energy

The FutureGen web site is www.fossil.energy.gov/programs/powersystems/futuregen.

Org 7.4: Weyburn–Midale Monitoring Organizations

What is it? The Weyburn–Midale Monitoring Organizations include the many organizations that participate in monitoring the two major commercial CO_2 flood EOR operations at Weyburn and Midale, Saskatchewan, under the International Energy Agency (IEA) Greenhouse Gas R&D Programme [Org 2.3].

Role played in Canadian CCS EnCana's Weyburn field is the largest closely-monitored CO_2 EOR operation in the world, with international participation and with many Canadian organizations involved since July 2000. Apache Canada's Midale CO_2 EOR operation will be included in the monitoring activities in the second phase of the project, beginning in 2005.

Description The Weyburn–Midale monitoring project is described, from different perspectives, on several pages in this compendium:

- Encana, the commercial operator of the Weyburn EOR operation [Org 8.1]
- Apache Canada Ltd., the commercial operator of the Midale EOR operation [Org 8.2]
- The IEA Greenhouse Gas R&D Programme, a sponsor of this international CO_2 monitoring of the fate of the injected CO_2 [Org 2.3]
- The first phase of the Weyburn project [Proj 14.3] (contains the most comprehensive list of projects)
- The final phase of the Weyburn–Midale project [Proj 17.3]
- National Energy Board, approval of transboundary transfer of CO_2 [Org 9.5]
- Hydrogeology of the Weyburn CO_2 Project for the prediction of CO_2 sequestration performance (University of Alberta) [Proj 11.1]

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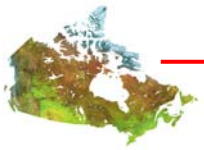
See also the IEA GHG R&D Programme web site at www.ieagreen.org.uk.



8. CANADIAN COMPANIES

Org 8.1: EnCana Corporation

What is it? Encana Corporation, with headquarters in Calgary, is a large natural gas producer, a large holder of gas and oil resources lands, and an active participant in the in situ recovery of oil-sands bitumen.

Role played in Canadian CCS Encana's Weyburn, Saskatchewan, oil field is the site of Canada's largest CO_2 sequestration project, with CO_2 supplied by pipeline from North Dakota.

Description The unique feature of Weyburn, a commercial-scale CO_2 miscible flood operation, is that it provides an opportunity to monitor the fate of the injected CO_2. It also provides experience in regulation, economics, and communications.

To take advantage of this opportunity, the project has for several years been the site of a world-scale research initiative, sponsored by the International Energy Agency's Greenhouse Gas R&D Programme, studying the sequestering of CO_2 in an oil reservoir.

Weyburn-related entries in this compendium can be found at the International Energy Agency Greenhouse Gas R&D Programme [Org 2.3], hydrogeology of the project [Proj 11.1], risk assessment [Proj 13.6], monitoring project phase I [Proj 14.3], monitoring project final phase [Proj 17.3], and approval of the CO_2 supply pipeline from the United States [Org 9.5].

The North Dakota–Saskatchewan pipeline now also supplies Apache Canada's EOR operation [Org 8.2].

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The Encana web site is www.encana.com.

Org 8.2: Apache Canada Ltd.

What is it? Apache Canada Ltd. is a subsidiary of Apache Corporation, a major U.S.-based oil and gas exploration and development company.

Role played in Canadian CCS Apache operates Canadian, commercial-scale CO_2 capture and storage projects.

Description This compendium describes two CCS projects, both located in the Western Sedimentary Basin:

- The Zama acid-gas EOR project, near Zama City, Alberta [Proj 11.3]
- CO_2 injection intoApache's Midale field in southeast Saskatchewan, the CO_2 coming from the same source in North Dakota and through the same pipeline that supplies CO_2 to the Weyburn-Midale oil fields [Proj 17.3]

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The Apache Corporation web site is www.apachecorp.com.

Org 8.3: Suncor Energy Inc.

What is it? Suncor, an integrated energy company, is one of Canada's largest producers of synthetic crude oil from the oil sands deposits of the Western Sedimentary Basin with both mining and in situ bitumen extraction and Fort McMurray–based upgrading operations.

Role played in Canadian CCS The company is developing technologies and commercial applications aimed at capturing CO_2 emissions from oil sands processing for long-term storage to avoid emission to the atmosphere.

Description Suncor is engaged in several significant initiatives, putting it among the more active Canadian companies in the field.

The company has an enhanced coalbed methane (ECBM) project south of Drayton Valley, Alberta [Proj 12.5], which it is managing on behalf of six other industry partners.

Suncor is one of five Canadian companies that have recently led the formation of the Integrated Carbon Dioxide Network (ICO_2N) along with six other industry participants. ICO_2N is working to establish the system and infrastructure needed to enable the sale, transport, and purchase of CO_2 [Org 1.6].

The company is also one of eight major international oil companies sponsoring the CO_2 Capture Project II (CCP2) to develop new breakthrough technologies to reduce the cost of CO_2 capture [Org 7.2].

Suncor has also participated in the Canadian federal government input to the Carbon Sequestration Leadership Forum, an international group that encourages improvement in carbon capture and storage technologies through coordinated R&D with international partners and private industry [Org 2.1].

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Org 8.4: Anadarko Canada Corporation

What is it? Anadarko Canada Corporation is a Canadian subsidiary of Anadarko Petroleum Corporation, a large, U.S.-based independent oil and gas exploration and production company.

Role played in Canadian CCS Anadarko Canada uses CO_2 injection for EOR at an operation in the Western Sedimentary Basin.

Description The company has operations in Alberta, British Columbia, Saskatchewan, and Northwest Territories. Its CO_2 EOR location is in southeast Alberta [Proj 11.2].

Anadarko is a member of the Enhanced Hydrocarbon Recovery Steering Committee of the Petroleum Technology Alliance Canada. The Committee's mandate includes CO_2 enhanced recovery [Org 1.3].

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Org 8.5: Penn West Energy Trust

What is it? Penn West Energy Trust is a large, Calgary-based oil and gas producer in the Western Canada Sedimentary Basin.

Role played in Canadian CCS The company has several CO_2 miscible flood operations and supports CO_2 research projects.

Description Penn West's major CO_2 storage project is its Pembina Cardium EOR pilot project [Proj 11.4].

Currently, Penn West operates a commercial CO_2 miscible flood at Joffre and a large hydrocarbon miscible flood at Swan Hills in Alberta. It also has working interests in the Virginia Hills miscible flood and the Midale CO_2 miscible flood.

The company also supports, or is involved in, other projects in this compendium:

- Optimizing CO_2 storage in oil reservoirs [Proj 11.10]
- Modelling and monitoring of CO_2 storage sites [Proj 13.5]
- A multi-player, multi-funder CO_2 monitoring project at Penn West's Pembina Cardium operation [Proj 14.4]

Penn West is a member of the Enhanced Hydrocarbon Recovery Steering Committee of the Petroleum Technology Alliance Canada. The Committee's mandate includes CO_2 enhanced recovery [Org 1.3].

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The Penn West web site is www.pennwest.com.

Org 8.6: Devon Canada

What is it? Devon Canada is a branch of U.S.-based Devon Energy Corporation, a large oil and gas producer in the United States, Canada, and other countries.

Role played in Canadian CCS The company is operating a CO_2 enhanced oil operation in the Western Sedimentary Basin.

Description Since 2004, Devon has been injecting CO_2 into its oil field in the Swan Hills area northwest of Edmonton [Proj 11.5].

Devon Canada is a member of the Enhanced Hydrocarbon Recovery Steering Committee of the Petroleum Technology Alliance Canada. The Committee's mandate includes CO_2 enhanced recovery [Org 1.3].

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The Devon Energy Corporation web site is www.devonenergy.com.

Org 8.7: SaskPower

What is it? SaskPower, a public utility, is the principal supplier of electricity in Saskatchewan.

Role played in Canadian CCS The company, a strong supporter of CCS development, is active in several organizations and projects.

Description The activities described in this compendium with which SaskPower is involved include these:

- Close links to the International Test Centre, Regina [Org 5.4]
- The Weyburn Phase I and Weyburn-Midale Final Phase CO_2 monitoring and storage projects [Org 7.4, Proj 14.3, Proj 17.3]
- The Canadian Clean Power Coalition [Org 8.2, Proj 3.5]
- Leader of the Saskatchewan Clean Coal Project [Proj 3.7]
- Simultaneous separation of CO_2 and SO_2 from industrial flue gases [Proj 4.9]
- Non-thermal plasma and flue-gas cleanup [Proj 4.13]
- Oxyfuel R&D consortium [Proj 6.4]
- Chair of the Clean Coal Technology Roadmap [Doc 1.2]

Saskpower is also a member of the Plains CO_2 Reduction Partnership [Org 2.8] and a collaborative partner in the new Saskatchewan Poly-Generation engineering study.

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The Saskpower web site is www.saskpower.com.

Org 8.8: Ferus Gas Inc.

What is it? Ferus Gas Inc. is a private, Alberta-based mutual fund trust specializing in the production, transport, and storage of industrial gases. Its primary products are liquid CO_2 and liquid N_2.

Role played in Canadian CCS For a number of years Ferus has supplied the western Canadian oil and gas industry with liquid CO_2 for well stimulation and EOR miscible flooding.

Description Among the company's major CO_2-related projects are these:

- The opening, along with Burlington Resources Canada Ltd., in December 2004 of a new $8 million CO_2 liquefaction facility, located adjacent to Burlington's Elmworth natural gas processing plant west of Grande Prairie, Alberta. The new facility cleans and liquefies approximately 160 tonnes per day of industrial-grade CO_2, which is removed from the gas stream at the Elmworth facility. The liquefied CO_2 is sold to the energy industry for use as a well stimulant and as a miscible flooding agent for enhanced recovery.
- The opening, along with ConocoPhillips Canada, in September 2004 of a new $11 million CO_2 liquefaction facility. Located near Medicine Hat, the CO_2 facility is adjacent to the ConocoPhillips-operated Empress gas plant. The new facility cleans and liquefies approximately 165 tonnes per day of industrial-grade CO_2 (together with sulphur capture). The CO_2 is sold to the energy industry for use as a well stimulant and miscible flooding agent.
- The opening, along with Keyspan Energy Canada, in May 2004 of a new $12.4 million CO_2 liquefaction facility. Located near Rimbey, Alberta, the CO_2 facility is adjacent to the Keyspan-operated Rimbey gas plant. The new facility cleans and liquefies approximately 285 tonnes per day of industrial grade CO_2 (together with sulphur capture). The CO_2 is sold to the energy industry for use as a well stimulant and miscible flooding agent.

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Org 8.9: The CO_2 Hub

What is it? The CO_2 Hub is an online trading platform that facilitates the exchange of CO_2 and related services between stakeholders along the CO_2 supply chain. The CO_2 Hub focuses on a market-driven business solution that encourages the use of CO_2 in enhanced petroleum recovery or storage projects and, at the same time, addresses the need and desire for an overall reduction of GHGs in Canada.

Role played in Canadian CCS The CO_2 Hub allows buyers and sellers of CO_2 to anonymously identify project partners for both near- and longer-term CCS projects. The market floor functionality offers all participants the greatest degree of choice, which can be critical to aiding in CO_2 price discovery in the early stages of this developing industry. Identified supply and demand for CO_2 can catalyze the development of the infrastructure required to move CO_2 from source points to enhanced petroleum recovery projects or storage or sink sites.

Description The trading platform of The CO_2 Hub is unique among commodity trading entities in that multi-tier auctions are automatically spawned to identify purification and transportation costs. Bidders can therefore reach partial price discovery before placing a final bid for the CO_2 offered by a seller. Once a transaction is accepted by the hosting party, the identities of the other parties are shared with the transaction participants. The CO_2 Hub does not take a transaction role; all legal contracts are completed offline between the parties. Participants may also register as buyers or sellers of emission reduction credits.

Another integral component of The CO_2 Hub is the Analyst's Hub, a section of the web site that shares links, facts, and figures pertaining to most aspects of CO_2 generation, capture, purification, transportation, compression, and storage. The Analysts' Hub can be accessed on The CO_2 Hub web site by anyone interested in learning more about the CO_2 supply chain.

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The CO_2 Hub web site is www.theco2hub.com.

Org 8.10: Canadian Clean Power Coalition

What is it? The Canadian Clean Power Coalition (CCPC) is an association of Canadian coal producers and coal-fired electricity producers that supports a program to address environmental issues.

Role played in Canadian CCS The Coalition is preparing to demonstrate the commercial feasibility of CO_2 capture from a coal-fired power plant. The Coalition includes non-Canadian members, bringing their experience and information to the program.

Description This compendium treats the CCPC as a project. For details, please refer to the project description [Proj 3.6].

CCPC has recently merged with the Clean Coal and Carbon Innovation Program (CCCIP) of EnergyINet. For more information, please refer to EnergyINet [Org 1.2].

Contact

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The Canadian Clean Power Coalition web site is www.canadiancleanpowercoalition.com.

Org 8.11: Computer Modelling Group Ltd.

What is it? Computer Modelling Group Ltd. (CMG) is a Calgary-based computer software technology and consulting company serving the oil and gas industry.

Role played in Canadian CCS CMG uses the CO_2 (and N_2) capability of its models in reservoir simulations for the Canadian oil and gas industry.

Description CMG specializes in reservoir modelling software. It has sales and technical support services in Calgary, Houston, Beijing, London, and Caracas.

In Canada, CMG's involvement in Canadian CCS includes these projects:

- CMG's own work developing simulation technologies for CO_2 storage [Proj 10.x] (project information could not be verified)
- Optimizing CO_2 storage in oil reservoirs (project led by the Alberta Research Council) [Proj 11.10]
- Enhanced coalbed methane and CO_2 storage piloting in Quinshi Basin, Shanxi Basin, China (ARC and others) [Proj 12.4]
- Integrated economic model for CO_2 capture and storage (ARC and others) [Proj 17.2]

Contact

Computer Modelling Group
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The Computer Modelling Group web site is www.cmgroup.com.

Org 8.12: Terasen Gas and Kinder Morgan Canada (as subsidiaries of Kinder Morgan Inc.)

What is it? Terasen Gas is the provincial natural gas distribution company in British Columbia. Kinder Morgan is a major petroleum transportation company based in Calgary. Their parent company, Terasen Inc., was purchased in November 2005 by Kinder Morgan Inc., a leading North American energy transportation and distribution company.

Role played in Canadian CCS Kinder Morgan Canada is expected to explore opportunities for CO_2 transportation in Canada.

Description Terasen Gas distributes natural gas to more than 880,000 customers, representing more than 95% of natural gas consumers in British Columbia. Kinder Morgan Canada provides petroleum transportation services from the Athabasca oil sands to Edmonton and from Alberta to British Columbia, Washington State, the U.S. Rocky Mountain region, and the U.S. Midwest.

Kinder Morgan, a U.S. company, is the owner and operator of more than 35,000 miles of pipeline and approximately 145 terminals in the United States. The company also has a large CO_2 pipeline network that embraces more than 1100 miles of pipeline and a net recoverable CO_2 reserve base in excess of five trillion cubic feet.

The new company has committed to conducting a comprehensive feasibility analysis of CO_2-related opportunities in Canada.

Contacts

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Mike Droppo
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The Kinder Morgan Inc. web site is www.kindermorgan.com.

Org 8.13: ZECA Corporation

What is it? ZECA Corporation was formed to develop technologies for zero emission carbon-based power production. Its work continues under the auspices of the individual participants.

Role played in Canadian CCS Canadian companies and governments participated.

Description ZECA was originally called the Zero Emission Coal Alliance; it then became the ZECA Corporation.

The original members from Canada included the Alberta Energy Research Institute, Barrick Gold Corporation, EPCOR Utilities Inc., Fording/Luscar/ATCO, Natural Resources Canada, Ontario Power Generation, SaskPower, The Coal Association of Canada, and TransAlta Corporation.

For more information, refer to the project in this compendium [Proj 5.1].

Contact

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The ZECA Corporation web site is www.zeca.org.

Org 8.14: TransAlta Corporation

What is it? TransAlta Corporation is a power generation and wholesale marketing company operating in Canada and internationally. The company operates coal-fired, gas-fired, and hydro plants, and plants running on other renewable energy sources.

Role played in Canadian CCS TransAlta has long played a role in Canadian CCS activities, from early days investigating the technology to recent trading in emission reduction credits.

Description TransAlta operates plants in Canada, the United States, Mexico, and Australia.

TransAlta was active in the early growth of Canada's CCS community, helping with conferences, presentations, and publications. Currently, the company is involved in the Integrated Carbon Dioxide Network (ICO_2N) [Org 1.6] and in evaluating carbon capture technologies through the Canadian Clean Power Coalition [Org 8.10].

Contact

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The TransAlta Corporation web site is www.transalta.com.

Org 8.15: The Delphi Group

What is it? The Delphi Group is an Ottawa-based consulting firm that offers to help private companies, governments, and organizations to manage risk and the process of complex change and to move toward a more competitive and sustainable future.

Role played in Canadian CCS Delphi is increasing its profile in strategies that involve CCS.

Description Delphi is a main contractor in an Asia–Pacific Economic Cooperation (APEC) initiative to promote CCS in APEC countries by identifying opportunities and following up with appropriate education [Org 2.7, Proj 16.2].

Contact

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The Delphi Group web site is www.delphi.ca.

Org 8.16: Air Liquide Canada Inc.

What is it? Air Liquide Canada is a branch of Air Liquide of France, a major international provider of industrial and medical gases and related services.

Role Played in Canadian CCS The company supplies CO_2 (and other gases) to the upstream oil and gas industry for EOR and reservoir life extension.

Description Air Liquide Canada is headquartered in Montreal, with offices across Canada including Edmonton and Calgary. The company supplies oilfield injection gases to many customers and is involved in several CO_2 projects described in this compendium:

- Petroleum Technology Alliance Canada [Org 1.3]
- Separation process and power plant configuration at the University of Waterloo [Proj 3.2]
- Enhanced coalbed methane recovery for zero-GHG emissions, led by the Alberta Research Council [Proj 12.6]
- The company was a member of the oxyfuel consortium at the CANMET Energy Technology Centre–Ottawa [Proj 6.4]

Contacts

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(403) 777 4700

Air Liquide Canada
Edmonton
(780) 438 5600

The Air Liquide Canada web site is www.ca.airliquide.com.

Org 8.17: ECOMatters

What is it? ECOMatters is a Manitoba-based testing laboratory and consulting company.

Role played in Canadian CCS The company is moving into risk assessment of geological storage of CO_2.

Description ECOMatters is working on three projects listed in this compendium:

- A project addressing whether CO_2 can be safely and permanently disposed of in deep geologic formations [Proj 12.11]
- Probabilistic risk assessment of the Weyburn CO_2 monitoring and storage project [Proj 13.6]
- An automated soil-gas grid sampling system [Proj 14.2]

Contact

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The ECOMatters Web site is www.ecomatters.com.

Org 8.18: HTC Purenergy (HTC Hydrogen Technologies Corp.)

What is it? HTC Purenergy is the commercial business name of Saskatchewan-based HTC Hydrogen Technologies Corp., an energy technology company.

Role played in Canadian CCS HTC Purenergy is commercializing CO_2 capture and storage technologies for EOR and commercial CO_2 uses, and is developing and commercializing H_2 production from natural gas and biofuels. HTC's H_2 production technology uses CO_2 as part of the reformation process and captures the balance of the CO_2 that is not being utilized.

Description The product development centre of HTC Purenergy is based at the International Test Centre (ITC) [Org 5.4] for CO_2 Capture, located at the University of Regina. The technologies have been developed through a Collaborative Research Agreement with the university and a Clean Air—CO_2 Sponsor Agreement with the ITC.

HTC Hydrogen Technologies has developed and aggregated intellectual property including patent rights and technology rights in the areas of CO_2 capture, capture solvents, CO_2 modelling, EOR utilizing CO_2, H_2 production (from natural gas, biofuels, and other fossil-fuel feedstock), and H_2 modelling.

Contact

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The HTC Purenergy web site is www.htcenergy.com.

Org 8.19: Greenhouse Gas Separation Systems Inc.

What is it? Greenhouse Gas Separation Systems Inc. (GGSSI) is a Canadian environmental technology and training company established primarily to commercialize a new patent pending process for the reduction (separation, capture, and sequestration) of GHG emissions such as CO_2, N_2O, and CH_4.

Role played in Canadian CCS GGSSI offers its separation and capture technology to Canadian CO_2 emitters. The technology could be applied to large emitters where geological storage is an option.

Description GGSSI was founded in 2000. It is built on designs and processes of a confidential and proprietary nature relating to the separation, capture, and sequestration of GHG emissions. In particular, the company has a patent pending for the Cerenzie Process, a GHG separation and capture technology invented by company's president, Albert Cerenzie.

The Cerenzie Process uses a combination of pure O_2 combustion, membrane separation, and ozonation scrubbing. The company states that its technology costs less to implement, does not require reduction in plant production, and can accommodate increased levels of production and emissions. The Canadian government–sponsored Environmental Technology Verification Program has independently verified that the pure O_2 combustion component of the Cerenzie Process can capture up to 92% of CO_2 from flue gases.

In addition to the Cerenzie Process, GGSSI offers products and services in the following areas:

- Identification and monitoring of gas composition
- GHG emissions reduction credits certification under the Kyoto Protocol
- Training of environmental monitors
- Training of workers in the oil and gas industry

Contact

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The Greenhouse Gas Separation Systems Inc. web site is www.ggssi.ca.

Org 8.20: Stratos Inc.

What is it? Stratos Inc. is a consulting company with a focus on environment, sustainable development, and corporate social responsibility.

Role played in Canadian CCS The company can provide advice on strategy to engage stakeholders in the capture and storage of CO_2.

Description Stratos is engaged in one project listed in this compendium, a study to ask how key stakeholders, in determining whether CO_2 storage is adopted, can be engaged in a discussion of its acceptability [Proj 16.1].

Contact

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The Stratos Inc. web site is www.stratos-sts.com.

Org 8.21: Cansolv Technologies Inc.

What is it? Cansolv Technologies Inc. is an international company headquartered in Montreal that designs and builds gas separation systems based on the patented Cansolv technology.

Role played in Canadian CCS Cansolv offers its product and services for the capture process for CO_2 emissions reduction and EOR.

Description Cansolv is engaged in two projects listed in this compendium:

- Capturing CO_2 from landfill gas–fired boilers [Proj 4.14]
- CO_2 capture, storage, and EOR in western Canada [Proj 4.15]

Contact

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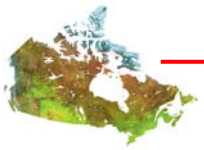
The Cansolv Technologies Inc. web site is www.cansolv.com.



Org 8.22: Glencoe Resources Ltd.

What is it? Glencoe Resources Ltd. is a privately held Canadian oil and gas exploration and production company that has operated in Alberta for more than 16 years.

Role played in Canadian CCS The company obtains CO_2 from two petrochemical facilities and pipes it to a Glencoe EOR project in Central Alberta.

Description At the end of 2005, Glencoe began shipping CO_2 by pipeline from its new facility adjacent to the MEGlobal Canada Inc. plant at Prentiss, Alberta. A second facility, adjacent to the NOVA Chemicals Joffre, Alberta, petrochemical complex, is under construction and is scheduled to commence operations in early 2006, with its CO_2 output also entering the pipeline.

When both facilities are operating, 220,000 tonnes of CO_2 will be piped and injected annually, making this CO_2 EOR project Alberta's largest.

Contact

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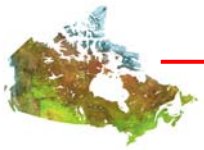
Calgary
(403) 233 8560



Org 8.23: Babcock & Wilcox Canada

What is it? Babcock & Wilcox Canada, a private company and wholly owned subsidiary of the Babcock & Wilcox Company of Barberton, Ohio, is a designer and supplier of fossil-fueled boilers to the utility, petrochemical, pulp and paper, and general industries and of nuclear steam generators to companies in Canada and abroad.

Role played in Canadian CCS Babcock & Wilcox Canada is a designer and supplier of oxyfuel combustion system for fossil fuel boilers.

Description The company participates in R&D, feasibility studies, pilot testing, planning, and implementation of commercial projects:

- Feasibility study for the Canadian Clean Power Coalition [Org 8.10]
- Member of the CETC-O Oxyfuel R&D Consortium, developing oxyfuel combustion technologies for CO_2 capture and storage [Proj 6.4]
- Pilot testing of coal oxy-combustion on a 5 million BTU/h small boiler simulator at the Babcock and Wilcox Company Alliance, Ohio, research center.
- Participant in Canada's Clean Coal and Carbon Capture and Storage Technology roadmaps [Doc 1.1, 1.2].
- Feasibility and preliminary engineering for conversion of an existing boiler to oxyfuel firing, and design development for oxyfuel firing of a new supercritical pulverized coal boiler, both capable of near-zero emissions.

Contacts

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The Babcock & Wilcox Company web site is www.babcock.com.

9. GOVERNMENT AGENCIES (NON-RESEARCH)—FEDERAL

Org 9.1: Natural Resources Canada, Office of Energy Research and Development

What is it? The Office of Energy Research and Development (OERD), located in Ottawa, coordinates the government of Canada's energy science and technology activities. Its role includes funding allocations, policy development, and representation of the federal government in Canada and abroad.

Role played in Canadian CCS OERD supports the development and implementation of S&T initiatives related to CCS at the federal, national, and international levels.

Description OERD manages the Program of Energy Research and Development [Org 11.2] and the Technology and Innovation Research and Development Initiative [Org 11.6]. For the most part, OERD does not award contracts directly. Contract award is the responsibility of other federal government organizations (such as CANMET Energy Technology Centres) that receive funds through OERD.

OERD also coordinates Canada's involvement in international energy S&T activities through linkages with the U.S. Department of Energy, the International Energy Agency, the European Union, the Asia–Pacific Economic Cooperation (APEC), and the North American Energy Working Group. These linkages support contacts with CCS developments elsewhere.

OERD, from its strategic position within Canada's energy S&T community, supports the investigation of CCS, such as the commissioning of this compendium.

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The Office of Energy Research and Development web site is www.nrcan.gc.ca/es/oerd.

Org 9.2: Natural Resources Canada, Oil Division

What is it? The Oil Division is a group within Natural Resources Canada that provides policy advice to the government on matters affecting Canada's oil economy. Actually, the division is within the Petroleum Resources Branch, which is in the Energy Policy sector of NRCan.

Role played in Canadian CCS The Oil Division is responsible for the implementation of the CO_2 Capture and Storage Initiative, an element of the federal government's Action Plan 2000.

Description The Oil Division monitors and analyzes developments in the oil industry and provides policy advice on the upstream and downstream oil economy. It carries out Canada's responsibilities in oil emergency preparedness.

The Division is also responsible for the implementation of the Carbon Dioxide Capture and Storage Initiative, an element of the federal government's Action Plan 2000, formed to address the problem of climate change. The Initiative is a program to advance our understanding of CCS and to promote its commercialization.

Components of the Initiative include policy research, advice, and development.

- The Initiative provided most of NRCan's funding to the Weyburn Phase I Storage and Monitoring Project [Proj 14.3].
- Another component of the Initiative is the CCS Incentive Program [Org 11.4], which funds selected pre-commercialization enhanced recovery projects.

Contact

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The Natural Resources Canada web site is www.nrcan.gc.ca.

Org 9.3: Natural Resources Canada, International Energy Policy Division

What is it? The International Energy Policy Division (IEPD) represents the federal government on energy and policy concerning energy and the environment, including Canadian and international negotiations on climate change. The Division is actually part of the Energy Policy Branch, which is in the Energy Policy sector of NRCan.

Role played in Canadian CCS The IEPD includes CCS in its mandate. CCS is now increasing in importance since publication of the IPCC *Special Report on Carbon Dioxide Capture and Storage* [Doc 1.5] and becoming of greater interest to the members of the United Nations Framework Convention on Climate Change [Org 2.5].

Description The IEPD has lead responsibility at Natural Resources Canada for developing and advancing NRCan's positions both within the Canadian delegation and at international climate change negotiations. The division works closely with the Department of Foreign Affairs and International Trade and Environment Canada to develop agreed-upon Canadian positions that will be put forward during international negotiating sessions. The division is called upon to provide policy analysis, advice, and recommendations to senior departmental officials and the minister of Natural Resources Canada. Key areas of work are defined in part by the provisions of the Kyoto Protocol and include forestry and agricultural sinks, Kyoto mechanisms, compliance, and the engagement of developing countries.

Contact

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The Natural Resources Canada web site is www.nrcan.gc.ca.

Org 9.4: Environment Canada

What is it? Within the government of Canada, Environment Canada is the lead department on sustainable development. It is responsible for most federal environmental programs and regulations.

Role played in Canadian CCS Some of the federal government's support of CCS comes from Environment Canada.

Description Environment Canada participates in several activities listed in this compendium.

- The department is one of many funders for two major Canadian initiatives:
  - The Alberta Research Council–led demonstration of enhanced coal methane production using CO_2 injection [Proj 12.6]
  - The monitoring of CO_2 fate at PennWest's Pembina Cardium CO_2 EOR pilot
- EC also supports public outreach projects [Proj 16.1, 16.3, 16.5].

The departmental programs with eligible CCS funding was are or were the Pilot Emissions Removal, Reductions and Learnings Initiative [Org 11.5], the Technology Early Action Measures (joint with Natural Resources Canada) [Org 11.7], and the Partnership Fund [Org 11.9]. The Partnership Fund is managed by the Domestic Climate Change Policy Directorate of the Strategic Policy Branch of EC.

Contact

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Domestic Climate Change Policy Directorate
Environment Canada
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Environment Canada also has a Greenhouse Gas Reductions Directorate, part of the Environmental Stewardship Branch, which is developing GHG emission targets for designated large industrial emitters. These proposed regulations would encourage the adoption of CCS as a means of reducing GHG emissions.

Contact

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Greenhouse Gas Reductions Directorate
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The Environment Canada web site is www.ec.gc.ca.

Org 9.5: National Energy Board

What is it? The regulatory powers granted to the National Energy Board (NEB) under the *National Energy Board Act* include authorization of exports of oil, natural gas, and electricity; authorization of the construction of interprovincial and international oil, gas, and commodities pipelines and international power lines; setting of tolls for pipelines under federal jurisdiction; and regulation of oil and gas activities on Canada lands in the north.

Role played in Canadian CCS As a result of the *Canada Transportation Act*, which came into force on 1 July 1996, jurisdiction over interprovincial and international commodity pipelines in Canada was transferred from the National Transportation Agency to the NEB. At that time, the definition of "pipeline" in the *National Energy Board Act* was broadened to include pipelines transporting commodities other than oil or gas (excluding municipal sewer and water lines).

Description The NEB has not yet played a large role in CCS, with the exception of approving the Canadian portion of the CO_2 pipeline from North Dakota to Saskatchewan in 1998. The Souris Valley Pipeline (NEB hearing MH-1-98) was the first hearing dealing with an application to the NEB for the construction and operation of a CO_2 commodity pipeline and is currently the only CO_2 pipeline regulated by the NEB.

The Souris Valley Pipeline connects with the Dakota Gasification Company CO_2 Pipeline at the Canada–U.S. border and transports CO_2 to the Weyburn oil field in Saskatchewan, where the CO_2 is used as a miscible flood for EOR. The CO_2 originates at the Great Plains Synfuels Plant near Beulah, North Dakota. The initial operating capacity of the pipeline, completed in late 1999, was 2.7 million m^3 daily.

Canada's Energy Outlook, last published by the NEB in 2003, used a scenario-based approach to examine various possible energy futures for Canada to the year 2025. A "techno-vert" scenario was used to represent a world in which technology advances rapidly and Canadians show a preference for environmentally-friendly products and cleaner-burning fuels. Forecasts based on the techno-vert scenario assumed significant use of "clean coal" technologies well-suited for CCS.

The NEB is embarking on an update of its *Energy Outlook for Canada* and intends to include possibilities for carbon sequestration in its analysis.

Contact

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The National Energy Board web site is www.neb-one.gc.ca.

Org 9.6: Foreign Affairs Canada, Climate Change and Energy Division

What is it? The Climate Change and Energy Division within Foreign Affairs Canada represents that department at major international climate change events such as the Conference of the Parties (COP) and the Meeting of the Parties (MOP) under the United Nations Framework Convention on Climate Change (UNFCCC). It fills the same representative role on important subsidiary bodies under the UNFCCC.

Role played in Canadian CCS The UNFCCC bodies cover CCS.

Description The Climate Change and Energy Division is responsible for the UNFCCC's Clean Development Mechanism (CDM) and Joint Implementation (JI) Office. The CDM and JI are both project-based GHG emissions reduction or removal mechanisms established under the Kyoto Protocol. Canada's participation is managed out of the CDM and the JI Office.

The CDM and the JI Office strengthen Canada's capacity to take maximum advantage of the Kyoto mechanisms and to assist Canadian entities in obtaining emissions reductions credits. The JI Office provides technical and financial assistance to Canadian entities and liaises with host countries to facilitate project implementation. The JI Office also assists participants looking for buyers by advertising project information to the Division's extensive database of Canadian companies and on the Division's password-protected web site.

Contact

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The CDM and JI Office web site is www.dfait-maeci.gc.ca/cdm-ji/offices_info-en.asp.

10. GOVERNMENT AGENCIES (NON-RESEARCH)—PROVINCIAL

Org 10.1: Alberta Environment

What is it? Alberta Environment is responsible for protecting that province's land, air, and water.

Role played in Canadian CCS The department's responsibilities include addressing climate change.

Description Alberta Environment published *Albertans and Climate Change: Taking Action*, which establishes a framework to reduce GHG emissions. The action plan champions CCS.

Toward this goal, the government supports

Technology development

- Innovative Energy Technologies (IETP) [Org 4.1]
- Alberta Energy Research Institute (AERI) [Org 4.4]
- Alberta Research Council (ARC) [Org 4.2]

Partnership and Collaboration

- Integrated CO_2 Network (ICO_2N) [Org 1.6]
- Energy Innovation Network (EnergyINet) [Org 1.2]
- Climate Change Central (C^3)

Regulatory and Risk Management

- CO_2 monitoring program

Projects supported by Alberta Environment and described in this compendium include

- the CO_2 sequestration capacity of Alberta's coalbeds [Proj 2.4].
- CO_2 fate at Penn West's Pembina Cardium field [Proj 14.4].
- citizen involvement and public attitudes [Proj 16.3, 16.5].

Contact

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The Alberta Environment web site is www.environment.gov.ab.ca.

Org 10.2: Saskatchewan Industry and Resources (ex Energy and Mines)

What is it? Saskatchewan Industry and Resources is that provincial government's business department, which is charged with stimulating entrepreneurial and business investment and development of the province's resource sector.

Role played in Canadian CCS The department's mandate includes support of CCS.

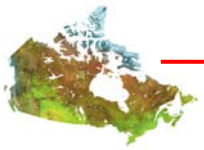
Description The Department's resource and economic policy monitors economic and market trends, policies, legislation, and impacts on industry performance, and provides analysis and recommendations on issues such as royalty and tax systems and climate change.

The department is one of the funders of a project that asks if CO_2 can be used to economically enhance the production of methane from coalbeds and what the fate of the injected CO_2 is [Proj 12.6].

Contact

Resource Development
Saskatchewan Industry and Resources
(306) 787 2528

The Saskatchewan Industry and Resources web site is www.ir.gov.sk.ca.



11. PROGRAMS—GOVERNMENT

Org 11.1: Natural Resources Canada, Opportunities Envelope

What is it? The Opportunities Envelope is a federal fund that provides financial support for GHG-reducing projects brought forward by the provinces and territories.

Note: The Opportunities Envelope, originally administered by Natural Resources Canada, has been closed down. The kind of support given can now be found in the Partnership Fund, administered by Environment Canada [Org 11.9].

Org 11.2: Natural Resources Canada, Program of Energy Research and Development

What is it? The Program of Energy Research and Development (PERD) is a federal government fund allocated annually to federal departments for energy research and development.

Role played in Canadian CCS Some program funds are earmarked for CCS R&D. Within that funding envelope, six major activities are carried out:

- Development of improved capture technologies
- CCS systems integration
- Assessment of sequestration resources
- Integration and optimization of capture technologies
- Development of sequestration science and technology
- Networking and dissemination activities

Description PERD is a long-standing fund devoted entirely to energy R&D. At about $50 million annually, it is the largest single pool of energy R&D funds within the federal government.

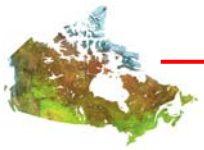
PERD funds are distributed annually to laboratories and programs under several federal departments, which in turn apply the funds (often accompanied by other non-PERD funds) to inhouse work or external contracts. The major recipient of PERD funds is Natural Resources Canada. Other departments receiving funds include Environment Canada, Agri-Food Canada, Health Canada, Industry Canada, Transport Canada, National Research Council of Canada, Public Works and Government Services Canada, Canada Mortgage and Housing Corporation, Fisheries and Ocean Canada, Northern Affairs Canada, and National Defence.

PERD supports the full range of energy R&D, with environmental concerns as a major focus. This includes the category Reduced Environmental Impacts of Canada's Electricity Infrastructure, with PERD activities focused on

- electric power generation from renewable energy sources.
- cleaner conversion of coal to electricity.
- small-scale or distributed generation, with an emphasis on combined heat and power applications.
- CCS.

The FY 2005–2006 funds allocated for CCS are $4.2 million.

PERD is managed by the Office of Energy Research and Development, Natural Resources Canada [Org 9.1].



Contact

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Office of Energy R&D, NRCan
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PERD information is available through the OERD web site at www.nrcan.gc.ca/es/oerd.

Org 11.3: The Natural Sciences and Engineering Research Council of Canada

What is it? The Natural Sciences and Engineering Research Council of Canada (NSERC) is the federal government's main vehicle for direct funding of university research at the individual project level.

Role played in Canadian CCS A growing number of CCS proposals are received each year and a growing number are approved.

Description NSERC is the national instrument for making strategic investments in Canada's capability in S&T. NSERC supports basic university research through discovery grants and project research through partnerships among universities, governments, and the private sector. It also supports the advanced training of highly qualified people.

The NSERC projects listed in this compendium are too numerous repeat in full here. They are instead grouped by Project section classification.

- 1 Capture, Transportation, and Storage [Proj 1.2]
- 3 Capture—General [Proj 3.1, 3.2, 3.4, 3.5]
- 4 Capture—Solvents [Proj 4.1, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12]
- 6 Capture—Oxyfuel [Proj 6.3]
- 7 Capture—Membranes [Proj 7.2, 7.3]
- 8 Capture—Other [8.1, 8.2, 8.3, 8.4, 8.5, 8.8, 8.11, 8.12]
- 11 Storage—EOR/EGR [11.1, 11.7, 11.9]
- 12 Storage—ECBM [Proj 12.1, 12.2, 12.3, 12.8, 12.10]
- 13 Storage—Reliability [Proj 13.1, 13.2, 13.4, 13.5, 13.7]
- 15 Storage—Other [Proj 15.1, 15.2, 15.3, 15.6, 15.7]

Contact

For the university scientists, refer to the name on each project page.

<u>For NSERC itself</u>

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Discovery Grants
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Org 11.4: Natural Resources Canada, Carbon Dioxide Capture and Storage Incentive Program

What is it? The Carbon Dioxide Capture and Storage Incentive Program is a major federal funding support for the commercialization of CCS.

Role played in Canadian CCS The Program provides partial funding for commercial-size storage projects in various geological settings.

Description The Program is designed to encourage oil and gas producers to incur production costs that can stimulate reductions in CO_2 emissions. It was initiated in 2004, to run for two years. A total of $15 million was available with a limit of $5 million for any one project. The funding for the initiative comes from Canada's Action Plan 2000 on Climate Change. Developed in consultation with industry and provinces in western Canada, this initiative complements provincial initiatives such as Alberta's CO_2 Projects Royalty Credit Program [Org 11.13]. It is designed to reduce duplication of effort for applicants in the Alberta program.

To be eligible, a firm must operate a project that injects CO_2 from a Canadian source into a geological formation for storage or disposal in Canada, and must demonstrate reasonable economic need for the project. The projects of four companies received funding approval under the first round of proposals:

For EOR (all projects are also supported by the Alberta Energy, CO_2 Projects Royalty Credit Program [Org 11.13])

- Anadarko Canada at its Enchant Arcs reservoir [Proj 11.2]
- Apache Canada Ltd. at its Zama pools [Proj 11.3]
- Penn West Petroleum at its Pembina field [Proj 11.4]
- Devon Canada Corporation's Swan Hills (unit 1) project in central Alberta [Proj 11.5]

For ECBM

- Suncor Energy at a coal seam located south of Drayton Valley, Alberta [Proj 12.5]

The Program is managed by the Oil Division, Energy Policy sector, Natural Resources Canada. Recommendations on the selection of projects were made by an advisory group that included experts from Natural Resources Canada and Environment Canada, with input from independent consultants.

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The Carbon Dioxide Capture and Storage Incentive Program web site is www.nrcan.gc.ca/es/erb/prb.

Org 11.5: Environment Canada, Pilot Emission Removals, Reductions and Learnings Initiative

What is it? The Pilot Emission Removals, Reductions and Learnings Initiative (PERRL) is a fund administered by Environment Canada. Through the fund, the federal government was prepared to buy verified emissions reductions from qualified eligible projects for a fixed price per tonne. (This Initiative is now closed to new applicants.)

Role played in Canadian CCS CO_2 capture and geological storage projects were eligible to receive funds for CO_2 stored. Although eligible, no CCS projects have yet been approved.

Description Under the PERRL Initiative four strategic sectors were eligible:

- Landfill gas capture and combustion
- CO_2 capture and geological storage
- Renewable energy
- Biological sinks

As a pilot project, PERRL was intended to help governments and private sector organizations learn about and better understand the important elements of emissions trading. Submissions were selected and reviewed according to the price-per-tonne offered by the seller.

The first auction round was held in the fall of 2002. That round was divided into two separate auctions: one covering landfill gas capture and combustion projects, and the other covering CO_2 capture and geological storage projects. Each of the two auctions had a purchase pool of $2.5 million available. Bids were accepted during October and December of 2002. Submissions were received for both project areas, although no contract in the CO_2 capture and geological storage auction was awarded. Four contracts for the purchase of more than 700,000 tonnes of GHG emissions reductions were awarded in the landfill auction.

A second auction round, held in 2004, covered renewable energy and biological sinks. The submissions for that round have been evaluated, but the results have not been announced pending finalization of all agreements.

A third and last auction round, for which the submissions closing date was February 2005, included all four strategic sectors. The results have not been released.

In December 2003, Alberta's Climate Change Central joined the program, providing funding and sitting on a committee that selects qualifying Alberta projects in the program's second and third rounds.

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The PERRL web site, which includes the results of the first round, is www.ec.gc.ca/perrl.

Org 11.6: Natural Resources Canada, Technology and Innovation Initiative

What is it? The Technology and Innovation Initiative (T&I) is a federal R&D funding initiative, with the projects carried out in partnership with stakeholders within and outside the federal government. Collaboration occurs under the terms specified in Memoranda of Understanding between the Office of Energy Research and Development of Natural Resources Canada, which manages the fund, and the performing organizations.

Role played in Canadian CCS Some of the funds support CCS technologies that will help achieve GHG reduction in the longer term.

Description Technology areas for the full T&I are

- cleaner fossil fuels.
- advanced end-use efficiency technology.
- decentralized energy production.
- biotechnology.
- hydrogen economy.

Project selection criteria include alignment with strategic objectives, potential GHG impact, partnerships and leveraged funds, and a dissemination strategy for results.

Support extends to the full range of technology development, from R&D (initial budget $115 million) to demonstration ($65 million, delivered through TEAM [Org 11.7]) to early adoption ($70 million).

The cleaner fossil fuels technology area is itself divided into three programs:

- Bitumen and heavy oil
- Unconventional gas supply
- Clean coal and CCS.

Integrated applications that cover more than one technical area are encouraged.

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T&I information is available through the OERD web site at www.nrcan.gc.ca/es/oerd.

Org 11.7: Natural Resources Canada, Technology Early Action Measures

What is it? Technology Early Action Measures (TEAM) is a federal interdepartmental technology investment program that supports late-stage development projects and first-time demonstration projects designed to reduce GHG emissions. It is managed by Natural Resources Canada, with Industry Canada and Environment Canada as co-chairs.

Role played in Canadian CCS CCS-related projects are eligible for TEAM support.

Description TEAM's funding is targeted at companies that develop new technologies to mitigate GHG emissions, but that need funding and technical assistance for the next stage—the stage of bringing the technology to market. TEAM acts as a strategic partner during this period. Many companies that have been involved in TEAM partnerships have subsequently received further private and public financing or have commercially replicated their technology in the marketplace.

Several federal government departments and agencies operate delivery programs that recommend projects for TEAM funding. Certain regional development agencies also make recommendations for TEAM funding.

TEAM has identified its technology demonstration priorities as

- cleaner fossil fuels.
- advanced end-use efficiency technology.
- biotechnology.
- hydrogen economy.
- decentralized energy production.

CCS is supported under the cleaner fossil fuels priority.

TEAM funding is expected to extend for another two years, at a level of more than $15 million annually.

Contacts can be made through government departments that are supported by TEAM, although contact can also be made directly with the TEAM Operations Office through the TEAM web site.

Contact

TEAM Operations Office
Natural Resources Canada

The TEAM web site is www.team.gc.ca.

Org 11.8: Climate Change Action Plan 2000

What is it? The Climate Change Action Plan was a major step in funding plans by the federal government to reduce Canada's GHG emissions. It included the AP2000 Technology Initiatives.

Role played in Canadian CCS The AP2000 Technologies Initiatives included CCS as an important objective.

Description The AP2000 Technology Initiative had two components:

- A Technology Development and Innovation Program
- A Canadian International Technology Initiative

The Technology Development and Innovation Program comprised five main initiatives (novel next generation research, applied R&D, roadmaps, networks, workshops) involving multiple organizations such as NRCan, Agriculture and Agri-Food Canada, the Natural Sciences and Engineering Research Council (NSERC), the National Research Council, Environment Canada, and Industry Canada, among others.

Four initatives that directly supported CCS are these:

- Novel Next Generation
  - NSERC [Org 11.3] delivers the Novel Next Generation Technologies Program through grants to university researchers.
  - Natural Resources Canada delivered Action Plan funds through the Innovation Research Initiative [Org 11.10] to federal and provincial researchers.
- Applied R&D
  - Made use of existing internal resources and technology located with federal labs. CCS projects were among the ultimate destinations of these funds: O_2/CO_2 combustion, CO_2 sequestration oil sands, and CO_2 gas hydrates.
- Roadmaps
  - Industry Canada–led initiative that developed four roadmaps: *CO_2 Capture and Storage, Clean Coal Technologies, Fuel Cell Commercialization,* and *Sustainable Fuels and Chemicals from Biomass.*
- Networks
  - NRCan-led initiative comprising three technology networks: CO_2 Management, Sustainable Community Energy, and Process Integration.

The Canadian International Initiative covered education, market analysis, and technology transfer, all with CCS components.

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Org 11.9: Environment Canada, Partnership Fund

What is it? The Partnership Fund is an element of Canada's 2005 Climate Change Plan for Canada that was announced in the April 2005 federal budget. Through the Fund, the federal government intends to engage the provinces and territories in taking action and aligning policy to work toward meeting Canada's Kyoto commitments.

Role played in Canadian CCS CCS is included in eligible technology and infrastructure investments.

Description As announced in Budget 2005, the government of Canada will work with provinces and territories to

- strike new agreements and improve existing ones.
- determine strategic investments on the basis of mutual priorities.
- finance, on a cost-sharing basis, major technology and infrastructure investments identified in collaboration with provinces and territories—for example, clean coal, phasing out coal-fired power plants, CCS pipelines, and extending the east–west electricity power grid.

The government of Canada will engage provinces and territories on the mandate of the Partnership Fund in the near future.

The Fund is administered by the Domestic Climate Change, Policy and Programs Division of the Strategic Policy Branch of Environment Canada.

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The Environment Canada web site is www.ec.gc.ca.

Org 11.10: Natural Resources Canada, Innovative Research Initiative

What is it? The Innovative Research Initiative (IRI) [for Greenhouse Gas Mitigation] is a fund designed to stimulate the initiation of high-risk exploratory scientific and technical ideas in natural sciences and engineering.

Role played in Canadian CCS CCS projects are eligible.

Description The IRI is aimed at government scientists in the provincial, territorial, and federal scientific community. It is a Climate Change Action Plan 2000 program, an outcome of the Technology Issues report on *Enhancing Technology Innovation for Mitigating Greenhouse Gas,* which recommended that Canadian capacity for advanced research in this field be stimulated through the government scientific community.

The IRI is complementary to the Natural Sciences and Engineering Research Council's [Org 11.3] Novel Next Generation Technology Initiative in Energy Research and Technology Related to Greenhouse Gas Mitigation, which targets the university community.

The IRI is intended to advance solutions to the climate change problem, and will yield other benefits such as increased energy efficiency, improved productivity, improved air quality, and reduced emissions of other effluents.

The proposed projects should be innovative and high-risk. They should not be a continuation of ongoing projects.

An IRI-funded project identified in this compendium examines high selectivity gas separation by mixed-matrix polymer–zeolite membrane [Proj 7.4].

The IRI is managed by the Office of Energy Research and Development [Org 9.1], Natural Resources Canada.

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Org 11.11: Sustainable Development Technology Canada

What is it? Sustainable Development Technology Canada (SDTC) is a not-for-profit foundation that finances and supports development and demonstration of clean technologies to address issues of climate change and other environmental problems. SDTC funds only consortiums representing a full spectrum of the supply chain and contributes, on average, about 33% of total eligible project costs.

Role played in Canadian CCS SDTC is open to applications for CCS projects.

Description SDTC is governed by a board of directors that reflects the broad interests of the public, private, and academic sectors in Canada. The board has overall responsibility for stewardship and strategic direction. Administration is handled by a staff of about 20, located in Ottawa.

SDTC works with an ever-growing network of stakeholders and partners to build the capacity of Canadian clean-technology entrepreneurs, helping them form strategic relationships, formalize their business plans, and build a critical mass of sustainable development capability in Canada.

To date, SDTC has completed seven funding rounds and allocated a total of $169 million to 75 projects. That amount has been leveraged with an additional $446 million in funding from other project partners for a total project value of $615 million.

Of the 75 funded projects, 2 address CCS:

- SDTC is a member of, and funding contributor to, a consortium led by Suncor Energy Inc. [Org 8.3], which is undertaking a pilot project on carbon sequestration and enhanced methane production in a closed cycle designed to capture CO_2 emissions, inject and sequester those emissions into a local subsurface coal reservoir, and produce enhanced volumes of coalbed methane as a result.
- SDTC is also one of the backers of an enzyme bioreactor project led by CO_2 Solution Inc. The bioreactor technology is designed to operate in an aqueous environment. It leverages mechanical and physical chemical principals, and the catalytic action of an enzyme, to sequester CO_2 in the form of inert bicarbonate compounds.

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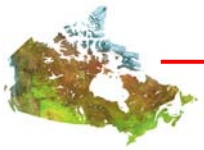
The Sustainable Development Technology Canada web site is www.sdtc.ca.



Org 11.12: Industry Canada, Technology Partnerships Canada

What is it? Technology Partnerships Canada was an instrument of Canada's Innovation Strategy and had partnered with the National Research Council (NRC) to provide precompetitive or precommercialization assistance to small- and medium-sized enterprises through the NRC's Industrial Research Assistance Program's national network of investment technology advisors.

Role played in Canadian CCS Eligible technology areas included CCS.

Description On 20 September 2005, the government announced that the program will be wound down, although current projects would continue to receive funding.

Org 11.13: Alberta Energy, CO_2 Projects Royalty Credit Program

What is it? The CO_2 Projects Royalty Credit Program provides royalty credits to companies that demonstrate the use of CO_2 in the enhanced development of Alberta's oil and gas resources.

Role played in Canadian CCS The program provides a financial incentive to share in the risks of projects incorporating CO_2 technology to expand production of Alberta's oil and gas resources.

Description Alberta Energy initiated the program in 2003 as a temporary feature of Alberta's royalty system. The program has total funding of $15 million in the form of oil and natural gas royalty credits. Demonstration projects based in Alberta that inject a mixture consisting mainly of CO_2 for enhanced recovery of oil or natural gas are eligible under the program. To improve project economics, companies will be able to earn royalty credits for up to 30% of approved costs in approved CO_2-enhanced recovery projects. The credits are not restricted to production from the project; they can be applied against a company's total petroleum or natural gas royalty liability.

In April 2004, four successful applicants to the program were announced. These companies would receive a total of $14.1 million in royalty credits for EOR projects:

- Anadarko Canada Corporation's Enchant Arcs project in southern Alberta [Proj 11.2]
- Apache Canada's Zama Keg River project in northwestern Alberta [Proj 11.3]
- Devon Canada Corporation's Swan Hills (unit 1) project in central Alberta [Proj 11.5]
- Penn West Petroleum Limited's Pembina Cardium project in central Alberta [Proj 11.4]

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The CO_2 Projects Royalty Credit Program web site is www.energy.gov.ab.ca/844.asp.

PART B: SCIENCE AND ENGINEERING PROJECTS

1. CAPTURE, TRANSPORTATION, AND STORAGE

Proj 1.1: Technical review of CO_2 sequestration in British Columbia and a systematic assessment of ultramafic rocks and their suitability for mineral sequestration of CO_2 (BC MEMPR/Victoria)

Goal To review technologies and CO_2 sources and sinks in support of decisions regarding CCS in British Columbia.

Question addressed Is CO_2 capture and storage a viable part of British Columbia's climate change strategy? Are ultramafic rocks in the province suitable for mineral CO_2 sequestration?

Project description This project had two phases. The first phase gave a preliminary review of potential CO_2 sinks and of major point sources. The second phase was the characterization of ultramafic rocks for mineral carbonation, which could be a niche opportunity for British Columbia where CO_2 point sources are located close to ultramafic rocks. This phase included field and laboratory work, part of which was carried out in collaboration with the Albany Research Center in the United States. The final report presents a methodology and key parameters for evaluating the mineral sequestration potential of ultramafic rocks.

Duration September 2002 to September 2004.

Who is involved B.C. Ministry of Energy, Mines and Petroleum Resources (BC MEMPR) [Org 4.7], University of Victoria [Org 5.1]

Funding level and funders 2002–2003: $30,000: BC MEMPR, plus a graduate student from the University of Victoria

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Proj 1.2: Optimisation of integrated CO_2 capture, transportation, and storage in Canada (Waterloo)

Goal To propose optimal national solutions to effectively implement CO_2 reduction, capture, transportation, and storage.

Question addressed What are the best options for mitigating, capturing, transporting, and storing CO_2 to meet specified reduction targets?

Project description In this project, optimization models will be developed, implemented, and integrated to aid in finding optimal solutions for CO_2 capture, additional treatment, transportation, and storage. These models will offer a multi-region, multi-technology decision framework for reaching the target CO_2 reductions in a cost-effective way. They will also account for predictable trends and interactions that occur in a dynamic setting of a country as a whole. The following tasks are included:

- Understand and quantify current and projected releases of CO_2 to the environment in a selected region.
- Assemble a database of available CO_2 capture options, their cost, comparison, and effectiveness.
- Model the CO_2 processing and transportation problem.
- Determine storage options, maximum capacity, and associated costs.
- Model the various decision scenarios using mathematical programming techniques and taking interactions into account.
- Test the model on a case study of OPG fossil-fuel boilers.
- Develop a solution strategy for the mathematical programming model.
- Implement the solution strategy and illustrate it on various case studies.

Duration 2005–2008

Who is involved University of Waterloo [Org 5.5]

Funding level and funders Total $467,000: Natural Resources Canada (Climate Change Technology and Innovation via the Clean Coal and Carbon Capture and Storage Strategy from CANMET Energy Technology Centre–Ottawa; Ontario Power Generation; University of Waterloo (NSERC funding); international support for two graduate students

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Proj 1.3: Development of a generalised systems scheduling framework for the operation of generating stations with CO_2 constraints in Canada (Waterloo)

Goal To develop a decision framework that will provide optimal strategies for operating a fleet of electric generating stations with CO_2 mitigation constraints.

Question addressed How can a utility optimize its fleet of generating assets to implement CO_2 reduction, capture, transportation, and storage?

Project description This research project will develop and test a systems scheduling framework, the context for which is the solution passed down from the regional planning problem (a fleet of generating stations using a variety of fuels with CO_2 capture and storage identified for specific boilers), and will determine the optimal operation and cost over a given period. The inputs have already been developed for the regional planning problem.

- Phase 1 focuses on gathering the necessary information to develop the simulator and perform the Ontario case study. Most of the data necessary to model power plants, CO_2 capture processes, and sequestration systems are already developed; the operation of the electricity markets and CO_2 trading credits will be the main focus of Phase 1.
- Phase 2 involves the development of models (unit operation, economic, and scenario models) and the incorporation of those models into the simulator. The simulator will be developed using GAMS, a modelling system developed for the World Bank.
- Phase 3 will apply the simulator to the Ontario electric utility sector. In this phase, the robustness of the developed model will be investigated to ensure that the model is comprehensive enough. The model will be validated by using a scenario representing the last three decades to test the simulation output.

Duration 2005–2008

Who is involved University of Waterloo [Org 5.5]

Funding level and funders $560,000: CANMET Energy Technology Centre–Ottawa (Natural Rresources Canada– Climate Change Technology and Innovation), Ontario Power Generation, University of Waterloo, governments of Malaysia and Saudi Arabia (grad students)

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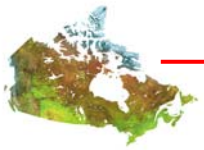

2. CHARACTERIZING SOURCES AND SINKS

Proj 2.1: Suitability of Canada's sedimentary basins for CO_2 sequestration (AGS)

Goal Assess the suitability of Canada's sedimentary basins for CO_2 geological storage on the basis of various geological, technical, and broad economic and societal criteria.

Question addressed What are the sedimentary basins in Canada with the largest potential for CO_2 geological storage where this technology is immediately applicable?

Project description Sedimentary basins have varying degrees of suitability for CO_2 sequestration in geological media as a result of different conditions and geological, hydrogeological, and geothermal characteristics. In addition, basin resources and maturity, infrastructure, and proximity to large stationary CO_2 sources play a significant role in assessing suitability of a basin for CO_2 storage in geological media.

The purpose of the project was to identify on a continental scale the suitability of approximately 70 sedimentary basins in Canada for CO_2 sequestration in geological media. On a regional scale, the suitability for CO_2 sequestration of the Alberta basin and of the Canadian part of the Williston basin (shared with the United States) was assessed both geographically and stratigraphically. A set of 15 intrinsic and extrinsic criteria, with several classes each, has been developed for the assessment and ranking of sedimentary basins in terms of their suitability for CO_2 sequestration.

The main conclusion of the study is that the deep parts of the Alberta Basin (Alberta and northeastern British Columbia) and the Williston Basin (southern Saskatchewan) have significant potential and are suitable for CO_2 geological storage. Sedimentary basins in Nova Scotia may have some potential if CO_2 storage in unminable coalbeds is demonstrated on a commercial scale. Other sedimentary basins in Canada are too small or shallow, are located in tectonically or climatically unsuitable regions, or are too far from CO_2 sources to be considered in the short- to medium-term.

Duration The project was completed at the end of 2002.

Who is involved Alberta Geological Survey, Alberta Energy and Utilities Board [Org 4.3]

Funding level and funders $540,000: Natural Resources Canada and the Alberta Energy and Utilities Board

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Proj 2.2: Sequestration of CO_2 in oil and gas reservoirs in western Canada (AGS)

Goal To estimate from reserves databases the CO_2 storage potential of gas reservoirs and oil pools in British Columbia, Alberta, Saskatchewan, and Manitoba.

Question addressed What is the potential and capacity for CO_2 storage in western Canadian oil and gas reservoirs?

Project description This project estimated the theoretical, effective, and practical capacities for CO_2 sequestration in oil and gas reservoirs in western Canada. The work was carried out using methodologies for estimating the sequestration capacity at depletion, for estimating the effect of underlying aquifers, and for screening oil reservoirs for CO_2 flood EOR and estimating their CO_2 storage capacity resulting from CO_2-EOR.

Provincial reserves databases in British Columbia, Alberta, Saskatchewan, and Manitoba record approximately 37,000 gas reservoirs and 10,500 oil pools. Results indicate that the effective CO_2 sequestration capacity in gas reservoirs is approximately 8.5 Gt CO_2. In contrast, the sequestration capacity in oil pools at depletion is only 450 Mt CO_2. Of the more than 10,500 oil pools, 4748 reservoirs were identified as suitable for CO_2-flood EOR. Most oil and gas pools in western Canada have small CO_2 sequestration capacity. Only 771 gas reservoirs and 98 oil reservoirs have an estimated CO_2 sequestration capacity greater than 1 Mt CO_2 each, but the cumulative capacity is 3.2 Gt CO_2 for gas reservoirs and 560 Mt CO_2 for oil reservoirs. Alberta has by far the largest CO_2 storage capacity in hydrocarbon reservoirs, followed by British Columbia (about 1 order of magnitude less), Saskatchewan (about another order of magnitude less), and Manitoba with negligible capacity (at most a few Mt CO_2).

Duration April 2000–March 2004

Who is involved Alberta Geological Survey, Alberta Energy and Utilities Board [Org 4.3]

Funding level and funders $600,000: Alberta Energy Research Institute, Alberta Energy and Utilities Board, and Natural Resources Canada

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Proj 2.3: Update and re-evaluation of CO_2 storage capacity in oil and gas reservoirs in Alberta and northeastern British Columbia (AGS)

Goal Based on updated data from reserves databases, to re-evaluate the CO_2 storage potential and capacity of gas reservoirs and oil pools in Alberta and northeastern British Columbia.

Question addressed What is the potential and capacity for CO_2 storage in Alberta and British Columbia's oil and gas reservoirs? What are the primary targets for CO_2 storage in oil and gas reservoirs?

Project description Previous work [Proj 2.2] developed a methodology for estimating the CO_2 storage capacity in oil and gas reservoirs and applied this methodology to western Canada using 2001–2002 provincial reserves databases. However, with increased exploration activity and continuous update and re-evaluation of reserves databases, those estimates were already out of date by the time the project ended. As an example, the most recent (2004) reserves databases for Alberta record approximately 1600 more oil reservoirs and several thousand more gas reservoirs than the versions used in the previous study. The objective of the study is to further improve the methodology for estimating CO_2 storage capacity in oil and gas reservoirs and to apply it to the most recent reserves databases available for Alberta and northeastern British Columbia, the two provinces with the largest capacity in Canada for CO_2 storage in oil and gas reservoirs. Another objective is to identify, on this basis, the primary targets for CO_2 storage in oil and gas reservoirs in Alberta and British Columbia based on size and timing of availability (depletion).

Duration April 2005–March 2006

Who is involved Alberta Geological Survey, Alberta Energy and Utilities Board [Org 4.3]

Funding level and funders $110,000: Alberta Department of Environment; British Columbia Ministry of Energy, Mines and Petroleum Resources; and the Alberta Energy and Utilities Board

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Proj 2.4: Evaluation of the CO_2 storage capacity in Alberta's coalbeds (AGS)

Goal To evaluate the potential and capacity for CO_2 storage in unminable coalbeds in Alberta.

Question addressed What is the potential and capacity for CO_2 storage in Alberta's unminable coalbeds? What are the primary target areas and coalbeds for CO_2 storage?

Project description Coalbeds provide an option and opportunity for geological storage of CO_2. The Cretaceous–Tertiary sedimentary succession in Alberta contains several coalbeds, of which the most important are, in ascending order, Mannville, Horseshoe Canyon, and Ardley. Currently these coalbeds are the target of intense exploration activity for coalbed CH_4. This project will evaluate the theoretical and effective CO_2 storage capacity of these beds by considering thickness, pressure, temperature, and adsorption capacity. Areas with high storage capacity (more than 200 $ktCO_2/km^2$) would be primary targets once this technology proves successful.

Duration January 2005–March 2006

Who is involved Alberta Geological Survey, Alberta Energy andUtilities Board [Org 4.3]

Funding level and funders $60,000: Alberta Department of Environment and Alberta Energy and Utilities Board (AEUB), with joint contribution of AEUB and Alberta Environment to the Plains CO_2 Reduction Partnership

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Proj 2.5: CO_2 storage capacity of deep coal seams in the vicinity of large CO_2 point sources in central Alberta and Nova Scotia, (assessment of) (GSC)

Goal To quantify the potential CO_2 storage capacity of coal seams near large CO_2 sources.

Question addressed How much CO_2 can be stored in known coal seams within reasonable distances of known CO_2 sources?

Project description This project uses the many oil and gas well intersections of deep coal seams to determine the distribution, thickness, and depth of deep coals. The project seeks to determine reservoir properties including pressure and temperature and, through experimentally derived CO_2 adsorption isotherms, to determine the in-place storage capacity expressed as megatonnes per square kilometer (Mt/km^2).

Duration 1997–ongoing

Who is involved Geological Survey of Canada, Natural Resources Canada [Org 3.3]

Funding level and funders Limited information made available—$275,000 in 2002–2003, $146,000 in 2005–2006: Natural Resources Canada and Canadian Clean Power Coalition

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Proj 2.6: CO_2 storage capacity estimate for northeast British Columbia (B.C. Ministry of Energy, Mines and Petroleum Resources/AGS)

Goal To estimate the CO_2 storage capacity of oil and gas pools and also to identify suitable regions to store CO_2 in deep aquifers in northeast British Columbia.

Question addressed What are the strategic opportunities for British Columbia to store CO_2 in geological media?

Project description Phase 1 of the project reviewed the current technical and political state of geological CO_2 storage, reviewed geological CO_2 storage options in British Columbia, and identified strategic opportunities for British Columbia in three different periods: pre-Kyoto, Kyoto, and post-Kyoto. As a result, CO_2 storage in oil and gas pools and deep aquifers located in northeast British Columbia was identified as a key opportunity for the pre-Kyoto and Kyoto time periods.

Phase 2 aims to improve the understanding of CO_2 storage capacity of oil and gas pools and deep aquifers in northeast British Columbia. This project includes a review of existing data, information, and updates about oil and gas reservoirs in northeast BC. The final product will be the report containing the estimate of CO_2 storage capacity of oil and gas pools, the timing of each pool's availability for CO_2 injection, and identification of suitable regions for CO_2 injection into deep aquifers.

Duration Phase 1: June 2004–March 2005; Phase 2: August 2005–March 2006

Who is involved B.C. Ministry of Energy, Mines and Petroleum Resources (BC MEMPR) [Org 4.7], Alberta Energy Utilities Board (Alberta Geological Survey) [Org 4.3]

Funding level and funders $20,000 (2004–2005): BC MEMPR; $25,000 (2005–2006): BC MEMPR; in-kind contribution of Alberta Energy Utilities Board

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Proj 2.7: The potential for CO_2 sequestration in British Columbia coal seams (B.C. MEMPR)

Goal To assess the CO_2 adsorption characteristics of major British Columbia coal fields.

Question addressed Are British Columbia coals suited to CO_2 adsorption and sequestration?

Project description This project proposed to collect coal samples from a number of coalfields in British Columbia and to analyze them for CO_2 isotherms. For each sample, CO_2 adsorption on coal, influence of coal rank and petrography on CO_2 adsorption, and influence of temperature on CO_2 adsorption were studied. The final report is an initial study of the CO_2 sequestration potential for coals in British Columbia.

Duration 2004–2005

Who is involved B.C. Ministry of Energy, Mines and Petroleum Resources (BC MEMPR) [Org 4.7]

Funding level and funders $30,000: BC MEMPR

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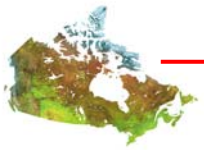

3. CAPTURE—GENERAL

Proj 3.1: Solid oxide fuel cell power generation systems (Waterloo)

Goal To simulate syngas-based —for example, coal syngas—solid oxide fuel cells (SOFCs) and to investigate the possibility of capturing CO_2 at reduced cost.

Question addressed Can use of SOFCs lead to CO_2 capture at minimum energy and economic cost?

Project description This research project will develop a robust SOFC model capable of predicting cell performance and loss in cell performance over time for a variety of operating conditions—in particular, feed composition (including hydrocarbons or light alcohols). Involves these subtasks:

- Determination of the kinetics of carbon deposition and its effect on the anode microstructure
- Implementation of a carbon deposition model
- Simulation of industrial tubular and planar cells operating with syngas
- Overall process simulation of SOFC base power generation with CO_2 capture

Duration 2004–2009

Who is involved University of Waterloo [Org 5.5]

Funding level and funders $108,000: NSERC

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Proj 3.2: CO_2 capture and mitigation technologies for Canada's power generation system (Waterloo and others)

Goal To develop advanced capture processes specifically suited to the recovery of CO_2 from fossil fuel power plants.

Question addressed What combination of separation process and power plant configuration is best for CO_2 capture?

Project description This project will investigate the integration of separation processes such as physical and chemical absorption, cryogenic distillation, and membranes with various power plant configurations such as those using coal, natural gas, integrated gasification combined cycle, and fuel cells. The project will determine the optimum means of incorporating capture processes into practical CO_2 recovery schemes.

Duration 2001–2005

Who is involved University of Waterloo [Org 5.5] in collaboration with Natural Rresources Canada (CANMET Energy Technology Centre–Ottawa) [Org 3.1], TransAlta Utilities [Org 8.14], Air Liquide [Org 8.16], and the IEA Greenhouse Gas R&D Programme [Org 2.3]

Funding level and funders $242,000: NSERC

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Proj 3.3: Improvements in efficiency and process modifications for CO_2 capture in western Canadian hydrogen plants (Waterloo)

Goal To develop, optimize, and cost process schemes for H_2 production at oil-sands plants in Alberta, based on hydrogen plants, combined with solid oxide fuel cells (SOFCs) or turbines with CO_2 capture (or both).

Question addressed What is the most effective strategy for producing hydrogen for oil-sands upgrading while capturing CO_2?

Project description This project comprises three tasks:

- Task 1 will develop the overall approach and integrate the results of the other two tasks.
- Task 2 will simulate and optimize a solid fuel–based hydrogen plant. AspenPlus models will be developed for IGCC using a wider range of fuels (pet coke, heavy oil residue), and alternative CO_2 capture strategies will be assessed.
- Task 3 is similar to Task 2, except that the focus will be on natural gas–fed hydrogen plants. Again, AspenPlus models will be developed for alternative reforming processes, and CO_2 capture options from existing and new hydrogen plants will be assessed. These results will be fed back into Task 1, where the integration of various hydrogen plants with various power systems, such as combined cycle, SOFC, and SOFC and turbine configurations. Solvent-based and oxyfuel strategies will both be examined.

The result will be a portfolio of options, with the capital and operating costs compared to current practice.

Duration 2004–2007

Who is involved University of Waterloo [Org 5.5]

Funding level and funders $212,000: Natural Resources Canada (CANMET Energy Technology Centre–Ottawa)

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Proj 3.4: Novel CO_2 separation processes for CO_2 mitigation (Waterloo)

Goal To develop reactive chemical membranes capable of separating CO_2 selectively from gas mixtures.

Question addressed Can membrane technology be combined with chemical solvent technology to produce a hybrid separation process for CO_2 separation?

Project description This research is aimed at developing novel techniques for capturing CO_2 from gaseous streams based on

- chemical soption of CO_2 by mixed solvents, and
- selective separation of CO_2 in reactive membranes.

Specific aspects to be studied are mass transfer enhancement by mixed solvents and facilitated transport of CO_2 in reactive membranes.

Duration 2003–2008

Who is involved University of Waterloo [Org 5.5]

Funding level and funders $46,600 annually for each of five years: NSERC

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Proj 3.5: High efficiency gas testing systems for CO_2 (GHG) capture and separation (Regina)

Goal To improve separation processes for recovery of CO_2 from industrial sources at the lowest possible capital and operating costs with minimum operating problems.

Question addressed What can be done to reduce the energy and economic costs of CO_2 capture by solvents?

Project description Work under this project investigated the mass transfer processes in high-efficiency structured and membrane packings, and studied the CO_2 absorption reaction characteristics of newly formulated solvents. On the basis of these studies, new structured and membrane packings and new solvent formulations were identified. Process integration and optimization analyses of CO_2 capture and separation from industrial sources including coal-fired power plants were performed to examine the impact of using the high-efficiency column packings, membranes, and formulated solvents developed in the project.

Duration 2000–2004

Who is involved University of Regina [Org 5.3]

Funding level and funders $34,800 (2000–2001); $34,800 (2001–2002); $34,800 (2002–2003); $34,800 (2003–2004): NSERC

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Proj 3.6: Canadian Clean Power Coalition [Org 8.10]

Goal To secure a future for coal-fired electricity generation in Canada.

Question addressed Can coal-fired electricity featuring CO_2 capture and storage be commercially viable in Canada?

Project description The Canadian Clean Power Coalition, an association of Canadian utilities and coal producers, the International Energy Agency and the U.S. Electric Power Research Institute, proposes the development, construction, and operation of a full-scale demonstration project by 2012. The resulting greenfield coal-fired power facility will remove GHGs and other emissions of concern.

The Coalition's proposal is expected to cost approximately CA$1 billion. Phase I of the project (conceptual engineering and feasibility studies) began in September 2001 and was completed in early 2004 with assessment of the technologies to be used in the demonstration (principally gasification, amine solvent stripping, and oxyfuel combustion). Phase II (technology gap analysis and business plan development) commenced in spring 2004 and was expected to be complete at the end of 2005. The main focus of Phase II was to investigate improvements to gasification technologies for low-rank coals (lignite and sub-bituminous), because most of the work in the world is on high-rank coals, although amine scrubbing and oxyfuel technologies will be examined again. Phase III (detailed engineering and construction) is expected to commence in 2006.

Duration Phase I: September 2001–early 2004; Phase II: Spring 2004–end 2005; Phase III: 2006–2012.

Who is involved Phase I: ATCO Power, EPCOR, TransAlta [Org 8.14], SaskPower [Org 8.7], Ontario Power Generation (OPG), NSPower, Luscar, Electric Power Research Institute, International Energy Agency (IEA) Coal Research, IEA GHG R&D Programme [Org 2.3]; Phase II: Basin Electric Power Cooperative joined, and OPG and IEA dropped out

Funding level and funders Phase I—$4.8 million from Coalition members, government of Canada, province of Alberta, province of Saskatchewan, Nova Scotia Department of Natural Resources; Phase II—$2.8 million from Coalition members, province of Alberta, and Natural Resources Canada

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Proj 3.7: Saskatchewan clean coal project: precommitment engineering and feasibility (SaskPower)

Goal To assess the feasibility of a coal-fired power plant operating in Saskatchewan with near zero emissions, and to position the project for construction if feasible.

Question addressed What is the most appropriate design for a Saskatchewan clean coal power plant with CO_2 and EOR, and what does it take to make the project economically viable?

Project description This project considers front-end engineering, design, and feasibility work for a potential near-zero emissions coal-fired electricity generating station in Saskatchewan. The project is the subject of an agreement between the federal and provincial governments and involves a continuing commitment from the federal government should the design work prove positive. The design basis for the plant would be 300 MW(e) net, with near zero emissions of GHGs and pollutants normally associated with coal-fired thermal power plants and an in-service date of 2011. The principal fuel would be Saskatchewan lignite; oxyfuel and solvent capture technologies will both be evaluated.

The project will also support design work needed to permit the use of captured CO_2 in EOR operations in Saskatchewan oil fields, including associated pipelines. The overall scope will also include retirement of some existing SaskPower generating units in need of replacement or refurbishment. Together with the facility described in Proj 3.8, the total cost of constructing these plants is estimated at $4.5 billion.

Duration 2006–2007

Who is involved SaskPower [Org 8.7] and partners yet to be named

Funding level and funders $20 million: SaskPower and federal and provincial governments

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Proj 3.8: Saskatchewan poly-generation project: technical and economic studies

Goal To assess the commercial feasibility of constructing a Saskatchewan poly-generation facility.

Question addressed Could a Saskatchewan facility producing chemicals and power be commercially feasible?

Project description This project involves the front-end engineering, design, and feasibility (technical and economic) of an industrial gasification and poly-generation facility near Belle Plaine, Saskatchewan. The project is proposed by an industry group, with the governments of Canada and Saskatchewan providing financial support. Feedstock alternatives, including biomass, lignite, and petroleum coke, will be examined during the feasibility assessment. The project seeks to deploy advanced technology to virtually eliminate emissions while producing H_2, N_2, steam, and CO_2 to produce fertilizer, electricity, and other commodities. SaskPower would be a major customer of the potential major project stream—namely, electricity. The project also involves proposals for CO_2 pipelines for EOR. Together with the facility described in Proj 3.7, the total cost of constructing these plants is estimated at $4.5 billion.

Duration 2006–2010

Who is involved The lead proponent is not yet in a position to make an announcement

Funding level and funders $20 million or more: Federal government (Climate Change Partnership Fund) and government of Saskatchewan, plus as yet undisclosed amount from industry participants

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Proj 3.9: Creation of a National Intelligence Centre on Near Zero Emissions Clean Coal Technologies (CETC-O)

Goal To establish a web-based "National Intelligence Centre" to provide relevant up-to-date information on clean coal technologies to allow informed investment decisions to be made, and to accelerate the development and commercialization of clean coal technologies in Canada.

Question addressed How can Canadian stakeholders be kept abreast of the latest developments in clean coal technology and associated CO_2 capture processes?

Project description In an effort to avoid duplication and foster collaboration in advancing near-zero emissions clean coal technology in Canada, the *Clean Coal Technology Roadmap* (see Doc 1.1) has advised that a web-based "National Intelligence Centre" be established to offer Canadian stakeholders access to screened information on clean coal technology developments that are happening throughout the world. The information would be presented in a concise way that is relevant to Canada's clean coal strategic needs. These are the major tasks to be undertaken:

- Design and maintenance of the Centre's web site
- Monitoring and annual reporting of national and international developments in clean coal technology
- Identification and provision of information on national and international programs that support the development of clean coal technology
- Preparation of profiles on key clean coal technology suppliers
- Reports concerning developments that affect the key drivers and impediments to adoption of clean coal technology
- Annual updates to Canada's *Clean Coal Technology Roadmap*

Duration 2006–2008

Who is involved CANMET Energy Technology Centre–Ottawa (CETC-O [Natural Resources Canada]) [Org 3.1]

Funding level and funders $249,000: CETC-O (Natural Resources Canada–Climate Change Technology and Innovation) and partners yet to be named

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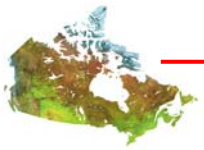

4. CAPTURE—SOLVENTS

Proj 4.1: Development of a CO_2 recovery and upgrading process [transl.] (UQAM)

Goal To develop a compact process and plant for capturing CO_2 from small industrial operations and for upgrading the CO_2 to industrial grade.

Question addressed Could CO_2 be captured effectively at industrial plants and sold as a raw material?

Project description This project examines CO_2 capture and subsequent upgrading to an industrial raw material through the use of a tertiary amine for CO_2 adsorption and selective desorption of NO_x, SO_2, and CO_2. The objective is to develop a compact process for use in small plants as part of the overall waste management system. The process would incorporate advanced plastic materials and pay particular attention to the corrosion and stability problems of amine solutions, the aim being a solution that is less toxic for the environment and recyclable. Economic aspects will also be examined to determine the degree to which the value of the CO_2 product stream can offset the costs of the process. Scientific aspects will be focused on studies of the fundamental physics and chemistry of the absorption and desorption mechanisms and optimization of design and operating parameters in industrial plants.

Duration 2001–2006

Who is involved Université du Québec à Montréal [Org 5.1]

Funding level and funders $35,000 annually (2001–2002 through 2004–2005): NSERC

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Note: Hausler seems no longer to be at this e-mail address, but no more current address is available.

Proj 4.2: University of Regina International Test Centre Consortium Program (Regina and others)

Goal To develop technical solutions that reduce dramatically the costs of solvent-based CO_2 capture from gas streams.

Question addressed How can the economic and energy costs of solvent-based CO_2 capture be reduced?

Project description This research program incorporates several projects that establish baselines for the current performance of solvent-based systems and develop improved solvent chemistry and process design to reduce capital costs, solvent degradation, corrosion, and parasitic energy loses. The work is carried out at the laboratory scale and at the pilot plant scale at a dedicated facility at the University of Regina, and at a semi-commercial scale at the Boundary Dam facility.

Phase I of the program was completed in 2005 (establishing the university facility and upgrading and refurbishing the Boundary Dam plant; establishing baseline performance and costs; testing mixed solvents; and working on packings, degradation, and corrosion). Phase II is just beginning, with a program that will evaluate and test new solvents, optimize the overall process and its integration into power systems (including product delivery and transport), conduct a detailed cost analysis of an integrated design, and develop training and innovation standards and training materials for operating a solvent-based CO_2 capture facility.

Duration Phase I: 2002–2005; Phase II: 2005–2009

Who is involved University of Regina's CO_2 Capture Group [Org 5.3] with the universities of Waterloo [Org 5.5], British Columbia [Org 5.6], and Calgary [Org 5.2]

Funding level and funders Phase I—$14 million for facilities: Western Economic Diversification, Canadian Foundation for Innovation, Sask Power, government of Saskatchewan; approximately $3 million operating: governments of Canada, Saskatchewan, and Alberta; Sask Power; TransAlta; Epcor; Nexen; EnCana; Petrobas; Fluor Daniel; and Luscar

Phase II—$3 million operating: Natural Resources Canada (Climate Change Technology and Innovation), Sask Energy and Mines, Alberta Energy Research Institute, EnergyINet, SaskPower, EnCana, E.ON (U.K.), Saudi Aramco, RITE (Japan), Babcock & Wilcox, Purenergy, KIER (S. Korea), universities of Regina and Waterloo, Imperial College

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Proj 4.3: Capture of CO_2 from combustion flue gases using amines (Regina)

Goal To reduce the cost of CO_2 capture with solvents through improved formulations, reduction of energy requirements, better operating practices, and better corrosion inhibition.

Question addressed How can the costs of amine-based solvent CO_2 capture processes be reduced?

Project description The International Test Centre (ITC) for Carbon Dioxide Capture is developing cost-effective technologies to reduce CO_2 emissions, especially those produced by the energy sector. This project will address the costs of amine-based CO_2 solvents by using a combination of strategies including efficient use of conventional solvents (such as higher MEA loadings), formulation of a new energy-efficient solvent (such as concentrated blends of MEA and MDEA), reduction of heat for regeneration, plus optimization and integration. To obtain a substantial reduction in the cost of CO_2 capture, new techniques of operation will also be tested. Currently, no data are available on CO_2 absorption rates, vapour–liquid equilibrium, corrosivity, degradation characteristics, heat of absorption, heat of regeneration, and so on, for highly concentrated CO_2-loaded MEA solutions or blends of MEA and MDEA. Also, because of the high cost and toxicity of current inhibitors, there is a need to develop less expensive and less toxic environmentally friendly corrosion inhibitors.

Duration 2004–2006

Who is involved ITC, University of Regina [Org 5.4]

Funding level and funders $83,000 annually for each of two years: Natural Resources Canada

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Proj 4.4: Development of energy-efficient CO_2 capture process using a rigourous design approach (Regina)

Goal To develop and evaluate new process configurations and formulated absorption solvents that have great potential for reducing energy consumption during solvent regeneration.

Question addressed Can alternative process configurations significantly reduce energy consumption for CO_2 capture?

Project description This project involves the development of a mechanistic model for predicting dynamic phenomena in the CO_2 absorption system. The model will provide detailed knowledge of gas stripping inside the regeneration column, thus assisting in developing new process configurations and screening or formulating energy-efficient solvents. An overall process simulation program is to be built by integrating the regeneration mechanistic model into the commercial process simulator. The simulation program will be used to determine the energy consumption of the new configurations against the conventional (base case).

Duration 2002–2003

Who is involved University of Regina [Org 5.3, 5.4]

Funding level and funders $22,141 (2002–2003): NSERC

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Proj 4.5: Fundamental studies of mass transfer with chemical reaction for CO_2 separation processes (Regina)

Goal To develop operational and design strategies to reduce the cost of solvent capture of CO_2.

Question addressed How to operate and design the CO_2 capture process to achieve the minimum cost of CO_2 capture?

Project description This project will carry out a series of absorption and regeneration experiments in pilot-scale columns fitted with structured packings. The project will also develop mechanistic models to predict mass transfer parameters and fluid dynamic phenomena in absorber and regenerator alike. The models will incorporate all crucial mechanistic components of gas absorption and regeneration, including thermodynamics, kinetics, fluid dynamics, and packing geometry. By combining the experimental results with the mechanistic models, overall process simulation and optimization will be carried out.

The project objectives are these:

- Provide insight into mass transfer and fluid dynamic behaviour in structured packings in absorbers and regenerators.
- Develop rigourous predictive models for gas absorption and solvent regeneration.
- Provide a cost-effective operational and process design strategy.
- Evaluate the cost reductions attributable to the proposed strategy.

Duration 2003–2007

Who is involved University of Regina [Org 5.3, 5.4]

Funding level and funders $21,000 (2003–2004); $21,000 (2004–2005): NSERC

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Proj 4.6: Separation of CO_2 from flue gases: alkanolamine degradation prevention studies (Regina)

Goal To understand the amine degradation process during CO_2 capture from flue gas streams, and to use this understanding to prevent amine degradation.

Question addressed How can the loss of solvent due to degradation be reduced?

Project description The project involved studies of the mechanisms of amine degradation under a variety of conditions typical of CO_2 capture processes.

Duration 2000–2004

Who is involved University of Regina [Org 5.3, 5.4]

Funding level and funders $21,500 annually for each of four years: NSERC

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Proj 4.7: CO_2 capture from coal-fired power plant flue gases using formulated amines: degradation prevention studies (Regina)

Goal To develop an "optimum degradation inhibitor" that will allow any formulated amine to be used for multi-component capture involving coal combustion flue gases (containing O_2, CO_2, SO_2, N_2, NO_x, and Hg) with the minimum possible degradation.

Question addressed How can the loss of solvent due to degradation be reduced?

Project description This project will perform a comprehensive study of the degradation of mixed amines formulated for CO_2 capture from coal-fired powerplant flue gases. The project will elucidate the degradation behavior and mechanism taking place in CO_2 capture in a system using mixed (formulated) amines that contain a corrosion inhibitor. The aim is to develop a framework or strategy for preventing or minimizing degradation. The approach is to develop an understanding of the mechanism of degradation prevention using scavengers and chelating agents and to develop formulations of effective amine degradation inhibitors for flue gas that contains CO_2, O_2, N_2, SO_2, and NO_x. The amine solvent formulated in this project will start with blends of MEA and MDEA and contain a corrosion inhibitor.

Duration 2005–2009

Who is involved University of Regina [Org 5.3, 5.4]

Funding level and funders $26,500 annually for each of five years: NSERC

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Proj 4.8: High-pressure solubility studies in acid-gas removal (Regina)

Goal To measure the solubility of CO_2 in promising physical solvents and non-alkanolamine solutions, and to develop new models.

Question addressed Are there non-alkanolamine solvents that perform better than MEA?

Project description This project screened 14 glycol ethers for their capacity for CO_2 absorption and hydrocarbon co-absorption. The solubilities of CO_2 in three promising non-alkanolamines were measured in a high-pressure cell up to 6500 kPa. A model correlated and then predicted the experimental data well. The reaction rates of CO_2 in non-alkanolamine aqueous solutions were measured in a stopped-flow cell, and the results were compared with those of MEA. Calorimetric and viscosity measurements shed new light on the interactions between water and the physical or alkanolamine solvents in terms of complex formation and the strength of the intermolecular forces involved.

Duration 2002—2006

Who is involved University of Regina [Org 5.3, 5.4]

Funding level and funders $24,750 in each of four years: NSERC

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Proj 4.9: New solvent development and mass transfer studies for simultaneous separation of CO_2 and SO_2 from industrial flue gases (Regina)

Goal To develop solvents for the simultaneous removal of CO_2 and SO_2 from power plant flue gases, and to test the efficacy, stability, and corrosion effects of these solvents.

Question addressed What are the best solvents and process parameters for stripping CO_2 from flue gases?

Project description This project had a broad scope that included

- screening solvents, including mixtures of physical and chemical solvents.
- characterizing kinetics of CO_2 absorption into MDEA and incorporation of this data into models.
- identifying low-toxicity corrosion inhibitors.
- measuring solvent degradation rates and associated mechanisms.
- measuring the effect of operating and design parameters on mass transfer rates in various structured packings.
- comparing the effect of process and operating parameters on stripping performance at pilot scale.
- comparing membrane performance with that of packed columns.
- developing improved membranes.
- performing economic and cost studies of CO_2 capture in power systems.
- simulating storage reservoirs.

Duration 1999–2003

Who is involved University of Regina [Org 5.3, 5.4]

Funding level and funders $91,500 (2000–2001); $88,500 (2001–2002); $88,500 (2002–2003): NSERC, with in-kind support from SaskPower, Nexen, and TransAlta

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Proj 4.10: Molecular design and solvent development of cost-effective processess for CO_2 capture from industrial gas streams (Regina)

Goal To develop novel absorption solvents that can capture CO_2 from industrial flue gas at much lower cost than conventional processes can.

Question addressed Can improved solvents for CO_2 capture be designed?

Project description This project worked on the design, synthesis, and molecular modelling of new, structurally relevant amines (especially amino alcohols) for stripping CO_2 from flue gases, with consideration of

- thermodynamic solubility, physical and transport property measurement, and kinetics.
- speciation and kinetic properties during degradation.
- corrosion properties and stability.
- performance of the solvents in an absorber.

The data generated will be used to develop tools to aid in the refinement and optimization during design and development of synthetic reactive solvents for CO_2 recovery.

Duration 2003–2006

Who is involved University of Regina [Org 5.3, 5.4]

Funding level and funders $172,500 (2003–2004); $172,000 (2004–2005): NSERC, with in-kind support from a consortium of industry and governments

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Proj 4.11: Fundamental studies of CO_2 (greenhouse gas) capture and separation using extra-high concentration formulated solvents (Regina)

Goal To develop improved (lowest cost and reduced operating problems) separation processes for CO_2 recovery from industrial gas streams.

Question addressed Can new solvents used at very high concentrations reduce the cost of capturing CO_2?

Project description This project will

- study the CO_2 absorption reaction characteristics of newly formulated solvents (up to five compounds) at extra-high concentration (up to 10 kmol/m^3).
- examine the reaction kinetics and absorption mass transfer of these high efficiency solvents.
- perform process integration and optimization analysis of CO_2 capture and separation from industrial sources (including coal-fired power plants) based on these new solvents.

Duration 2004–2009

Who is involved University of Regina [Org 5.3, 5.4]

Funding level and funders $35,124 (2004–2005): NSERC

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Proj 4.12: Comprehensive corrosion studies and development of low-toxicity corrosion inhibitors for CO_2 separation process (Regina)

Goal To conduct a comprehensive study of corrosion behaviour, to identify the corrosion mechanism and develop a predictive model, and to search for low-toxicity chemical compounds that can replace the current toxic corrosion inhibitors used in CO_2 separation processes.

Question addressed Can low-toxicity corrosion inhibitors for CO_2 capture processes be found and used in place of heavy-metal corrosion inhibitors?

Project description This project focuses on developing low-toxicity corrosion inhibitors to respond to environmental concerns, to reduce the cost of waste disposal, and to prepare for more stringent regulations for chemical use. Corrosion experiments will examine the influence of process parameters on corrosion behaviour. The results will be used to test various corrosion mechanistic models. The performance of low-toxicity corrosion inhibitors will be experimentally evaluated under static and dynamic conditions. The minimum dosage or injection rate for each low-toxicity inhibitor will be determined. Also, long-term performance will be evaluated so as to determine the frequency of dosage addition or injection needed for satisfactory inhibition.

Duration 2000–2007

Who is involved University of Regina [Org 5.3, 5.4]

Funding level and funders $61,900 (2000–2001); $61,900 (2001–2002); $61,900 (2002–2003); $65,000 (2003–2004); $65,000 (2004–2005); $25,000 (2005–2006); $25,000 (2006–2007): NSERC grants and scholarships

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Proj 4.13: Non-thermal plasma multi-pollutant control technology for flue gas pre-cleaning before amine CO_2 scrubbing operation (CETC-O)

Goal To develop an effective means of removing pollutants from flue gases before amine stripping of CO_2.

Question addressed Can thermal plasmas clean flue gas impurities that would otherwise contaminate amine CO_2 sorbents?

Project description This research project will explore the use of radical-shower plasma-generating technology as a flue-gas-cleaning technology before flue gas is fed to an amine-based CO_2 separation process. In the radical-shower plasma mode, reagent and pollutants are charged and excited locally at low electricity input to trigger chemical reactions and convert pollutants to harmless solid substances that can be captured by particulate control devices. The plasma technology is designed to remove SO_2, NO_x, and Hg from flue gas in coal-fired facilities.

A plasma radical-shower reactor will be designed and tested on a flue gas stream to determine effectiveness in controlling levels of pollutants. Operating conditions such as flue=gas temperature, plasma discharge voltage, and reagent utilization rates will be investigated.

This technology will be tested in the lab before a proposed test on a flue-gas slipstream from an operating coal-fired power plant is attempted.

Duration 2004–2007

Who is involved Initial work on the radical-shower plasma technology was done by Chang at McMaster University. This project will be carried out at the CANMET Energy Technology Centre–Ottawa [Q. Zuang; Org 3.1]. Subsequent field testing is tentatively planned by SaskPower [Org 8.7] at their Boundary Dam or Poplar River plant, in conjunction with the International Test Centre at the University of Regina [Org 5.4].

Funding level and funders $570,000 over three years: Natural Resources Canada (Climate Change Technology and Innovation), SaskPower, Ontario Power Generation, and Nova Scotia Power

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Proj 4.14: Capturing CO_2 from landfill gas–fired boilers (Cansolv and others)

Goal To demonstrate a novel process for capturing CO_2 in flue gas and for converting the CO_2 into precipitated calcium carbonate.

Question addressed Is it technically and economically feasible to capture CO_2 in flue gas from typical industrial boilers?

Project description This technology grew from earlier projects that introduced ways of removing SO_2 from process emissions, which the proponents successfully implemented at Noranda, ConocoPhillips, and Bayer. In this project, Cansolv would demonstrate the technology in a landfill gas–fired boiler at a large pulp-and-paper mill, which will then use the captured CO_2 to manufacture precipitated calcium carbonate that will be used in paper manufacturing.

Duration 2003–2006

Who is involved Cansolv Technologies Inc. [Org 8.21]., Pulp and Paper Research Institute of Canada, Enviro-Acces Inc.

Funding level and funders $4.6 million: Sustainable Development Technology Canada and consortium members (Cansolv, Enviro-Accés Inc., Pulp and Paper Research Institute of Canada)

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Proj 4.15: CO_2 capture, storage, and enhanced oil recovery project in western Canada (Cansolv and others)

Goal To build and operate a commercial plant capturing CO_2 at a coal-fired facility in western Canada by 2009.

Question addressed Is the capture of CO_2 from coal-fired plants for use in EOR a near-term commercial opportunity?

Project description Cansolv is developing a project to construct and operate a 5000 ton/day CO_2 capture plant to extract CO_2 from the flue gases of a coal-fired plant in western Canada. The project is proposed for development in three phases:

- Conduct a pilot-plant demonstration at a coal-fired facility, using Cansolv's mobile multipollutant pilot plant, while concurrently completing a project pre-feasibility study.
- Install a commercial demonstration plant producing approximately 500 ton CO_2/day (by 2007), trucking the CO_2 to an oil field.
- Build, own, and operate a full-scale plant with capacity of some 5000 ton CO_2/day (by 2009), and pipeline the CO_2 to oil fields in the region.

Duration 2006–2009

Who is involved Cansolv and other partners (under consideration) [Org 8.21]

Funding level and funders Not yet available

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5. CAPTURE—GASIFICATION

Proj 5.1: Emission-free coal and carbon energy technology with integrated CO_2 capture (ZECA and others)

Goal To develop and commercialize an integrated zero emission technology for converting carbon-based fuels to power or H_2 (or both).

Question addressed What is the most energy-efficient and cost-effective means of converting the energy in carbon-based fuels to usable forms while capturing and sequestering CO_2 and eliminating other air emissions?

Project description ZECA Corporation was a private carbon management venture that embodied a U.S.-Canadian collaboration that succeeded the Zero Emission Coal Alliance in 2001. Technical and business plans to design, construct, and operate a pilot plant within a five-year period were developed.

ZECA was the exclusive world licensee (from the University of California) of patented emission-free coal and carbon energy technology (E-F technology) that was identified at Los Alamos National Laboratory and Louisiana State University. This technology uses hydrogasification and calcium oxide reforming to produce H_2 from coal, petroleum coke, bitumen, heavy oil, biomass, and so on, while simultaneously producing "pure" CO_2 for sequestration. The H_2 may be used for upgrading (oil sands), production of electricity, or off-site sales. Initially, H_2-fueled turbines may be used for generating electricity, but ultimately, development of a robust, sulphur-tolerant, solid oxide fuel cell was seen as important to achieve "water-free," zero emissions electricity production using this technology.

ZECA's work continues under the auspices of individual participants.

Duration 2000–2005

Who is involved Shareholders in ZECA [Org 8.13] included Canadian and American utility, mining, manufacturing, and coal interests and was managed from Calgary, Alberta

Funding level and funders Approximately $1.0–1.5 million: Shareholders, Natural Resources Canada, Alberta Energy Research Institute, and industrial participants

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Proj 5.2 : Zero emissions hydrogen production via gasification (CETC-O)

Goal To develop the scientific and engineering knowledge for an advanced fossil-fuel-fired technology that produces H_2 and electricity with no CO_2 or other air emissions.

Question addressed Can chemical looping cycles improve efficiencies and lower costs for converting coal (and other carbonaceous fuels) to H_2 and electricity while capturing CO_2?

Project description The project will entail the fundamental research and process simulation required for basic engineering of a chemical looping gasification process featuring enhanced H_2 production and CO_2 capture. Simultaneously, a hot gas clean-up module with in situ syngas monitoring will be designed and installed. The approach will use dual fluid beds for the carbonation and gasification step and the sorbent regeneration step. H_2 production would be integrated into the gasification process, achieving production of H_2 and separation of impurities simultaneously.The project will also address the effective control of particulate and gas-phase contaminants at high temperature and high pressure through the use of cyclones and barrier filters. Fixed-bed reactors will be examined to capture alkali species with a regenerable sorbent.

The project would evaluate existing Canadian fuels and sorbents using an entrained flow gasifier, would research high-temperature multi-pollutant sorbents, develop an engineering design package for a typical plant in the Western Canadian Sedimentary Basin, develop an in situ optical measurement system to measure component concentrations, and develop partnerships and tools for commercialization.

Duration 2004–2008

Who is involved CANMET Energy Technology Centre–Ottawa, Natural Resources Canada [Org 3.1]

Funding level and funders $2.1 million over 4 years: Natural Resources Canada (Climate Change Technology and Innovation), Canadian Clean Power Coalition, Alstom, universities of Toronto, Ottawa, and British Columbia

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Proj 5.3: Feasibility of integration of membrane reactor with gasification for clean coal application (CETC-O)

Goal To evaluate CANMET's H-membrane in a water–gas shift membrane reactor for producing a pure H_2 stream and a stream highly concentrated in CO_2, from the product stream of the gasification of coal.

Question addressed Can the integration of coal gasification technology and membrane reactors be an effective route to zero CO_2 emissions?

Project description Membrane reactors can circumvent the thermodynamic limitation found in conventional water–gas shift reactors, because they can separate H_2 as it is produced. Removal of H_2 moves the water–gas shift reaction toward more H_2 and an enriched high-pressure CO_2 stream. CANMET's proprietary H-membranes will be evaluated for viability in a water–gas shift membrane reactor, treating pre-combustion streams obtained from the gasification of coal. Actual coal gasification streams obtained from the "CANMET coal gasifier" [Proj 5.2] will be used in the evaluations. Water–gas shift membrane reactor studies will be carried out at atmospheric pressure on facilities separate from the coal gasifier. Membrane reactor operating parameters such as water-to-CO ratio and product sweep rate will be studied. Membrane reactor compatibility with various coal gasification product streams, and membrane reactor efficiency for CO conversion, H_2 removal, and CO_2 concentration will be determined. CANMET H-membranes will also be evaluated by industry (Engelhard and Technip KTI [Kinetics Technology International]) for water–gas shift and reformer applications. Completion of this project would provide a logical decision point and risk analysis of an integrated coal gasification and membrane reactor study, with an estimate of process requirements and any economic gains.

Duration 2005–2008

Who is involved CANMET Energy Technology Centre–Ottawa (CETC-O), Natural Resources Canada [Org 3.1]

Funding level and funders $375,000: CETC-O (Natural Resources Canada, Climate Change Technology and Innovation), Englehard and Technip KTI

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Proj 5.4: Increasing gasifier availability via improved refractory and injector designs (CETC-O)

Goal To develop suitable gasifier fuel injector designs and refractory lining materials by improving the technology associated with these components, which are the largest contributors to gasifier planned and unplanned shutdowns.

Question addressed What can be done to address key technical barriers to adoption by utilities of IGCC plants (low availability because of refractory failure and reactant injector failure)?

Project description The project will develop improved fuel injector designs and refractory lining materials for the gasification of western Canadian coals for power generation and H_2 production. The approach will include better fundamental understanding of the failure processes and a new computational fluid dynamics model (pilot-plant proven). New designs will be evaluated using a variety of fuels, including petroleum coke, asphaltenes, a mixture of petroleum coke and lignite from Saskatchewan, and sub-bituminous coal from Alberta. This project consists of the following activities:

- Investigation of refractory materials under slagging gasification conditions
- Computational fluid dynamics modelling of the fuel injectors and combustion zone for dry fuels
- Process simulation with ASPEN Plus
- Engineering design and manufacture of new fuel injectors for feeding dry fuels
- Engineering design and manufacture of new slagging gasifier vessel
- Installation of the injector, gasifier, and shell temperature monitoring instrumentation into the CANMET Energy Technology Centre–Ottawa (CETC-O) pilot-scale gasification plant
- Pilot-plant evaluation of the refractory materials selected by the Albany Research Center and CETC-O
- Pilot-scale evaluation of the dry fuel injector designs for the selected feedstocks
- Demonstration of a fibre-optic temperature-sensing device in conjunction with LxSix, a Canadian fibre optic manufacturer

Duration 2005–2008

Who is involved CETC-O (Natural Resources Canada) [Org 3.1], Albany Research Centre, LxSix Photonics

Funding level and funders Approximately $1.5 million: CETC-O (NRCan–Climate Change Technology and Innovation), Albany Research Centre, LxSix Photonics

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6. CAPTURE—OXYFUEL

Proj 6.1: Closed gas turbine cycle project (Waterloo/Carleton)

Goal To evaluate advanced power cycles involving oxyfuel combustion for their ability to produce power and capture CO_2.

Question addressed What is the most cost-effective means of producing electrical power while capturing CO_2?

Project description This project evaluates the technical and economic performance of various closed gas turbine– and fuel cell–based cycles utilizing oxyfuel combustion to produce power and capture CO_2. The work program includes simulation activities and primary research.

Work on the Raven zero emission gas turbine is focused on the design and construction of a 70 KW(e) natural-gas-fired generator set using pure O_2 combustion with CO_2 recirculation. Design parameters and concepts learned from the pilot-scale work will be used to model the operations of a 100 MW(e) industrial-scale facility. Work is underway to develop a simulation of a solid oxide fuel cell (SOFC), which can be integrated with a gas turbine bottoming cycle. A particular aspect of the work on SOFC is the operation with syngas that could originate from biofuel or from coal syngas. In this project, the focus has been on evaluating the effect of the CO concentration in the syngas on the SOFC performance.

Duration April 2002–March 2006

Who is involved Carleton University [Org 5.1] is doing the work on the Raven zero emission gas turbine; University of Waterloo [Org 5.5] is doing the SOFC simulation work

Funding level and funders $850,000: Climate Change Action Plan Program [Org 11.8] through the CANMET Energy Technology Centre–Ottawa

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Proj 6.2: Advanced Brayton-cycle-based zero emission power plants burning fossil fuels (Carleton)

Goal To design a 100 MW(e) plant utilizing a Brayton-cycle-based semi-closed zero emission design fueled with an O_2–CO_2–gaseous fuel.

Question addressed What process or design or material changes are needed to optimize combustion turbines for oxyfuel use?

Project description This work extends that of Proj 6.1. Four major elements are proposed:

- Continue to study the implementation of a Brayton-cycle-based semi-closed zero emission design for a nominal 100-MW(e) plant, supplemented by new models to assess the performance and the relative cost of the options available.
- Continue to study the utilization of working fluids other than air in gas turbine turbomachinery, including the development of design tools. The design tools will be validated using a commercially available computational fluid dynamics code (probably CFX) and turbomachinery rig testing as applicable.
- Continue to study combustion systems for O_2–CO_2–gaseous fuel (natural gas and syngas) utilization, including the development of design tools. The design tools will include non-equilibrium models for the composition of products leaving the combustor. The design tools will be used for a preliminary combustor design and to provide estimates of performance parameters such as temperature profiles and pressure loss across the combustor. The design tools will be validated using commercially available state-of-the-art computational fluid dynamics and chemical kinetics codes.
- Initiate the study of new materials and coatings required for this design by identifying the expected failure modes and proposing solutions. Coatings specifically designed for this project will be manufactured and tested in a test rig that will be designed and manufactured.

Duration 2006–2008

Who is involved Carleton University [Org 5.1]

Funding level and funders $470,000: CANMET Energy Technology Centre–Ottawa (Natural Resources Canada–Climate Change Technology and Innovation) and Carleton University

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Proj 6.3: Decarbonization of fossil fuels for CO_2 mitigation (Waterloo)

Goal To advance and optimize the efficiency of the oxyfuel process for carbon-based combustion, and to develop a process for the thermal decomposition of CH_4 to H_2 and C.

Question addressed Can the efficiency of the oxyfuel process be improved, and what is the least CO_2-intensive way of producing H_2 from CH_4?

Project description This research project includes two separate themes:

- Examination of oxyfuel combustion as an alternative to post-combustion capture of CO_2 by chemical solvents. The approach is to burn the fuel in a mixture of air and O_2, and recycle part of the flue gas so as to increase the concentration of CO_2. The goal is to optimize the overall efficiency of such a power plant, using simulation, by trading off the penalties associated with the production of O_2 against the penalties inherent in conventional CO_2 separation.
- Examination of the thermal decomposition of CH_4 to produce H_2 and C, thereby reducing the CO_2 emissions associated with more conventional reforming of natural gas.

Duration 2000–2004

Who is involved University of Waterloo [Org 5.5]

Funding level and funders $86,000: NSERC

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Proj 6.4: CETC-O Oxyfuel R&D Consortium: Development of oxyfuel combustion technologies for CO_2 capture and storage

Goal To develop oxyfuel combustion as a cost-effective technology for CO_2 capture from fossil fuel–fired processes.

Question addressed What is the most cost-effective technology for capturing CO_2 from fossil-fired combustion systems?

Project description The research program is aimed at improving the understanding of oxyfuel combustion with a wide range of fossil fuels and the impact of that combustion on plant design and pollutant abatement technologies. Pilot-scale testing under the program is carried out in a 0.3 MW(th) vertical combustor capable of firing coal, oil, and natural gas with varying degrees of O_2 concentration in a flue gas recirculation stream to produce a near pure stream of CO_2 that can be readily captured by direct compression.

Oxygen combustion and the performance of the downstream clean-up technologies including electrostatic precipitators, bag houses, scrubbers, and condensing exchangers are being studied under the guidance of an industry and government consortium management committee. Elements of the program included the development of a novel low NO_x oxyfuel burner and novel integrated mercury, sulphur, and particulate control technology options for a variety of fossil fuels. Integrated flue gas pretreatment for CO_2 purification and removal and multi-pollutant capture mechanisms are also being studied in a condensing heat recovery and scrubbing environment. Boiler simulation tools are being developed for use in HYSYS and other commercial software. Outputs of the program are confidential to partners; however, several papers are in the public domain.

The research program also includes development of a semi-closed-cycle micro gas turbine, a conceptual design of a zero emission 100 MW industrial gas turbine, and investigation of the integration of solid oxide fuel cells (SOFCs) into a gas turbine cycle to generate power while producing a CO_2-rich stream for capture.

Duration Started in 1994, currently in Phase 8

Who is involved Oxyfuel R&D Consortium: CANMET Energy Technology Centre–Ottawa [Org 3.1], plus consortium members including (at present) SaskPower [Org 8.7], Ontario Power Generation, International Energy Agency GHG R&D Programme [Org 2.3], U.S. Department of Energy, Alberta Government (Alberta Energy Research Institute [Org 4.4]), Babcock & Wilcox [Org 8.23]; (in the past) EPCOR, TransAlta [Org 8.14], NSPower, and Air Liquide [Org 8.16]

Funding level and funders Approximately $1 million annually: Consortium members and Natural Resources Canada (Program of Energy Research and Development)

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Proj 6.5: Oxyfuel field demonstration project (CETC-O and others)

Goal To enhance market acceptance of oxyfuel combustion with CO_2 capture as a commercial viable and attractive near-zero emissions technology.

Question addressed Is oxyfuel combustion a commercially attractive technology for minimizing CO_2 emissions and other air pollutants, what are the technology gaps, and what are the requirements for commercial demonstrations?

Project description The oxyfuel process includes fossil-fuel combustion in an oxygen-rich environment, integrated flue gas treatment, CO_2 compression, CO_2 pipeline and storage, and use of CO_2 in enhanced oil, gas, and coalbed methane recovery. This project is aimed at identifying, promoting, and fostering opportunities for the commercial demonstration of oxyfuel combustion as means of reducing CO_2 and other air emissions. To support site-specific commercial demonstrations, elements of this project involve process modelling, feasibility engineering, and cost studies to address technology gaps and needs. Efforts are also focused on developing novel processes for CO_2 capture and compression that could be used to increase awareness of the latest oxyfuel technology developments, solicit interest in technology demonstration, and develop partnerships and project proposals for commercial demonstrations.

Duration 2001–2006

Who is involved CANMET Energy Technology Centre–Ottawa [Org 3.1] and a number of industrial partners

Funding level and Funders $1.38 million: Government of Canada (Climate Change Action Plan); currently seeking industrial partners for additional projects in areas described above

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Proj 6.6: Zero emission oxyfuel combustion technologies for clean fossil fuels (CETC-O and others)

Goal To develop a new generation of oxyfuel combustion processes and compact combustor or boiler systems that will further improve plant efficiency and reduce CO_2 capture cost.

Question addressed Can second-generation oxyfuel processes lead to practical compact boiler systems and be cheaper and more efficient at capturing CO_2 from flue gases?

Project description This project will investigate new variants of oxyfuel combustion processes by minimizing the flue gas recycle and by controlling the flame temperature through other means. The oxy-steam combustion approach will be investigated as a means of moderating the boiler temperature to allow conventional materials to be used in the design while offering improved heat transfer. These developments may lead to smaller boilers and greatly reduced flue gas volume. The reduction in flue gas volumes will in turn reduce the size of the flue gas treatment equipment, leading to lower capital and operating costs for plants with CO_2 capture.

Another area of investigation will be performance optimization of the CO_2 compression train (for flue gas compression) and CO_2 purification using new processes.

The project also includes process modelling and experiments to investigate the advantages of hybrid cycles in the oxyfuel process to help improve overall fuel-to-electricity efficiency.

The project involves pilot-scale testing and process simulation, computational fluid dynamics modelling and costing to assess the scale-up of the technologies.

Duration 2004–2008

Who is involved CANMET Energy Technology Centre–Ottawa [Org 3.1] and Carleton University [Org 5.1]; industrial partners are being solicited

Funding level and funders Approximately $3 million: Natural Resources Canada (Climate Change Technology and Innovation), CANMET Energy Technology Centre–Ottawa Oxyfuel Consortium, Carleton University

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Proj 6.7: Novel oxyfuel burner with in situ emissions control of multi-pollutant and CO_2 (CETC-O and others)

Goal To develop

- a novel oxyfuel burner that utilizes fuel and oxidizer streams to suppress pollutants, enhance and control heat transfer, and increase combustion efficiency, and
- a multi-pollutant and mercury-capture sorbent technology.

Question addressed How can the oxyfuel process be improved?

Project description The first part of this work seeks to improve heat transfer and flame quality by developing a novel oxyfuel burner design that exploits the oxyfuel flame structure—specifically, the temperature and combustion radical profiles. By aligning these profiles, soot and NO_x can be dramatically reduced, along with other pollutants, and a lower flame temperature can be realized while the radiant heat transfer can be maintained or increased. If successful, this design would increase combustor efficiency, reduce gas stream pollutants, and reduce the flue gas recirculation ratio needed to cool the oxyfuel flame. The second part of this work proposes a multi-pollutant and mercury capture technology, which further increases the CO_2 concentration in the flue gas and reduces the load on downstream pollution control systems. By adding nanostructure TiO_2–based sorbents to the fuel stream or by introducing them slightly downstream of the combustor, pollutants such as trace toxic metals, mercury, and other species may be eliminated. The two technologies will be tested in tandem and separately. Tasks will include equipment design and construction, testing in the "vertical combustor facility" at CANMET Energy Technology Centre–Ottawa (CETC-O), and optimization and scale-up incorporating economic and technical aspects alike.

Duration 2006–2008

Who is involved CETC-O (Natural Resources Canada) [Org 3.1] and Washington University (St. Louis, Missouri)

Funding level and funders $440,000: CETC-O (Climate Change Technology and Innovation), Ameren, Washington University

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Proj 6.8: Integrated high-efficiency oxyfuel combustion process for CO_2 capture comprising slagging combustor, air separation, and gas turbine technologies (CETC-O and others)

Goal To develop second-generation oxyfuel combustion to improve the efficiency and further reduce CO_2 emissions by integrating with reduced- or no-CO_2 recycle, gas-cooled slagging combustor and gas turbine technologies.

Question addressed How can the oxyfuel combustion process be made more effective?

Project description This project builds on the work under Proj 6.1, 6.3, and 6.5. The project has two principal tasks: design of an advanced gas-cooled slagging cyclone combustor, and design of an efficient gas turbine using the by-product gas stream from an air separation unit as the working fluid. The project will include these elements:

- Development of efficient and optimized process models for second-generation oxyfuel combustion
- Computational fluid dynamics analysis, modelling, and design of the gas-cooled slagging combustor and N_2 turbine for second-generation oxyfuel combustion
- Identification of critical operating parameters and the optimum operating range of the system
- Feasibility studies on the individual components and the overall system
- Development of new control schemes for operation of a gas-cooled slagging combustor, N_2 turbine, and the overall system

Duration 2006–2008

Who is involved CANMET Energy Technology Centre–Ottawa (CETC-O) [Org 3.1], Carleton University [Org 5.1], Federal Institute for Materials Research and Testing (FIMRT [Germany])

Funding level and funders $287,000: CETC-O (Natural Resources Canada–Climate Change Technology and Innovation), Carleton University, and FIMRT

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Proj 6.9: Electrical power production from circulating fluidized bed combustor boilers with CO_2 capture (CETC-O and others)

Goal To test CO_2–O_2 firing of a circulating fluidized bed boiler to verify low conventional emissions and a nearly pure stream of CO_2.

Question addressed Is an oxyfuel circulating fluidized bed boiler a better route to clean coal (zero or near-zero emissions of pollutants while producing a pure stream of CO_2)?

Project description This project will demonstrate CO_2–O_2 firing in a circulating fluidized bed combustion (CFBC) boiler using the 1 MW CANMET Energy Technology Centre–Ottawa (CETC-O) pilot-scale CFBC boiler. The existing facility will be upgraded to allow O_2 firing with flue gas recycle and to create a test platform capable of verifying the concept of O_2 firing in a CFBC boiler. Subsequent phases include testing CO_2–O_2 firing with a variety of Canadian coals and biomass to verify that the pilot-scale CFBC can be run in this mode. A number of optimized long-term tests will be done to ensure that agglomeration and other issues are not potential showstoppers. An overall economic evaluation of oxyfuel CFBC will be carried out.The program will allow the concept to be fully tested at a reasonable pilot-scale level, verifying that low conventional emissions (NO_x, SO_x, CO, Hg, and unburned hydrocarbons) can be achieved alongside the production of a near pure CO_2 stream for sequestration.

Duration 2005–2008

Who is involved CANMET Energy Technology Centre–Ottawa [Org 3.1], with CANMET Materials Technology Centre, National Research Council Institute for Chemical Processing and Environmental Technology [Org 3.4], and Terra Industries

Funding level and funders $700,000: Natural Resources Canada (Climate Change Technology and Innovation via CETC-O's Clean Coal CO_2 Capture and Storage Strategy)

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7. CAPTURE—MEMBRANES

Proj 7.1: Hollow-fibre membranes for CO_2 separation (ARC/Waterloo)

Goal To develop and implement micro-porous hollow-fibre technology in CO_2 separation.

Question addressed Are hollow fibres a more effective way of separating CO_2 from gas streams than amine solvents are?

Project description This project is pursuing new ways to improve the efficiency of CO_2 separation from synthetic flue gas using micro-porous hollow-fibre technology. Using micro-porous hollow fibres as the absorber in a packed tower has the following advantages as compared with conventional packings:

- High gas-to-liquid contact area
- Gas and liquid flow rates that may vary in a wide range without flooding
- Hollow-fibre membrane contactors that may be operated in any orientation
- Low operating pressure

This project is also examining inorganic salt–based solvents, which offer advantages such as low solvent cost, no solvent oxidation and degradation, and lower desorption energy.

The project objectives are these:

- Development of a technology using micro-porous hollow-fibre membrane modules as gas-to-liquid contactors to achieve efficient, low-cost CO_2 capture from flue gas
- Application of this technology for post-combustion CO_2 capture and pre-combustion gas cleaning
- Potential to incorporate this technology with currently available liquid processes in next 5–6 years

To date, the project has developed a micro-porous hollow-fibre membrane module, including selection of materials and a design that overcomes the wet-ability changing issue and achieves much more practical operation time and CO_2 absorption efficiency. Excellent CO_2 absorption efficiency is also exhibited when an inorganic salt–based solvent was employed.

Duration 1999–2007

Who is involved Alberta Research Council [Org 4.2] and University of Waterloo [Org 5.5]

Funding level and funders $1.1 million: Alberta Research Council, Natural Resources Canada, University of Waterloo, Alberta Newsprint Company, Alberta Energy Research Institute (proposed)

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Proj 7.2: Gas permeation properties of commercial polyphenylene oxide and cardo-type polyimide hollow-fibre membranes (Ottawa)

Goal To investigate the effect of operational parameters on the performance of commercial polyphenylene hollow fibres and cardo-type polyimide hollow fibres.

Question addressed Are these membranes effective in separating mixtures of CO_2 and CH_4, and O_2 and N_2?

Project description Based on pure N_2, O_2, CH_4, and CO_2 permeation experiments, it was concluded that cardo-type hollow fibre membranes are good candidates for separating O_2 and N_2, and CO_2 and CH_4. The average O_2 and N_2 permselectivities are 3.9 and 5.7 for PPO and cardo-type polyimide hollow fibres respectively, and the average CO_2 and CH_4 permselectivities are 16.4 and 36.0 for PPO and cardo-type polyimide hollow fibres respectively. The CO_2 permeance has an increasing trend with feed pressure values of 210 and 110 GPU at 100 psig for PPO and cardo-type polyimide hollow fibres. Gas mixture transport was determined by three different concentrations of CO_2 in mixtures of CO_2 and CH_4 gas (5%, 10%, and 24.6% CO_2, balance CH_4) at room temperature, and three different stage-cuts for each feed concentration. The feed side and permeate side pressures were 100 psig and atmospheric respectively. It was concluded that at stage-cuts proportional to feed CO_2 concentrations (vol.%), the obtained separation factors were approximately equal.

Duration 2004–2005

Who is involved University of Ottawa [Org 5.1]

Funding level and funders $30,000: Sharif University, Iran; NSERC; University of Otttawa

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Proj 7.3: Pressure-swing permeation and integrated membrane and absorption processes for enhanced separation of gases (Waterloo)

Goal To integrate membrane permeation with pressure-swing adsorption for improved separation of gases.

Question addressed Can the combining membranes and pressure-swing absorption improve the separation of CO_2 from other gases?

Project description A dynamic membrane process called pressure-swing permeation was developed to be operated in a cyclic fashion similar to that of pressure-swing adsorption. The ultimate objective was to synergistically integrate the two processes to enhance overall separation efficiency. The idea was to use the pressure swing to increase the pressure of the permeate from the membrane unit by pressurization with the high-pressure feed, facilitating subsequent adsorption separation for further purification.

Duration 2000–2004

Who is involved University of Waterloo [Org 5.5]

Funding level and funders $24,000 annually for each of four years: NSERC

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Proj 7.4: High-selectivity gas separation by mixed-matrix polymer–zeolite membranes (NRC and others)

Goal To investigate inorganic–organic mixed-matrix membranes that exhibit selective gas separation performance in excess of the performance limits for typical polymeric membranes.

Question addressed Can high-selectivity membranes based on polymer–zeolite composites offer a more attractive means of separating CO_2 from flue gases?

Project description This project explores avenues for preparing zeolite-based mixed-matrix composite membranes and for improving the performance of those membranes by eliminating defects and voids that occur at the polymer–zeolite interfaces. The membranes combine the highly gas-selective rigid pore-channel structure of inorganic zeolites with the processability of polymer matrices. A number of gas separations of industrial interest are being investigated, including O_2 and N_2, acid-gas removal from natural gas, H_2 and CO_2, and CO_2 capture from flue gas.

Duration 2002–2006

Who is involved National Research Council of Canada, Institute for Chemical Process and Environmental Technology [Org 3.4]; National University of Singapore

Funding level and funders $650,000–National Research Council, an international collaborative agreement with Singapore, Natural Resources Canada (Innovative Research Initiative)

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8. CAPTURE—OTHER

Proj 8.1: New solid sorbents for carbon dioxide capture (UQAM)

Goal To identify and prepare solid CO_2 sorbents.

Question addressed Are there solid sorbents that will work better than liquid amines for capturing CO_2?

Project description This project seeks to identify an efficient solid sorbent for CO_2. The sorbent would be characterized by high rates of CO_2 capture at 2 mmol/g, long-term regeneration capacity, and a small difference in adsoption and desorption temperatures. Sorbents will be prepared by grafting amino groups onto a high surface area support such as activated carbon or silica.

These sorbents will be characterized by a variety of physical and chemical techniques and their usefulness for CO_2 adsorption will be evaluated.

Duration 2004–2007

Who is involved Université du Québec à Montréal [Org 5.1]

Funding level and funders 96,000 (2004–2005): NSERC

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Proj 8.2: CO_2 scrubbing—The dry route (Ottawa)

Goal To identify and test new solid adsorbents for CO_2 scrubbing that address the shortcomings of liquid-based scrubbing systems.

Question addressed Can a dry scrubbing approach be more effective and economic than the conventional wet scrubbing approach?

Project description This project will develop technology based on recyclable solid adsorbents and direct interaction of CO_2 with amines grafted onto the pore walls of very high surface area honeycomb-like nanoporous silica. This dry scrubbing approach would not be accompanied by corrosion or generation of contaminated water. Because of diminished mass transfer resistance, the reaction of the amine groups protruding from the pore walls with gas-phase CO_2 should be quantitative and faster than than that seen in conventional liquid-phase systems. The developed adsorbents will be tested with QuestAir Technologies' Pulsar process, which features adsorbent-coated laminates instead of fixed-bed columns.

Duration 2001–2004

Who is involved University of Ottawa [Org 5.1]

Funding level and funders $136,160 (2001–2002); $106,160 (2002–2003); $108,160 (2003–2004): NSERC

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Proj 8.3: Novel adsorbents for acid-gas removal (Ottawa)

Goal To produce CO_2 adsorbents with greater adsorption rates and capacities than present commercial adsorbents have.

Question addressed Can a material be developed specifically to overcome the current limitations of commercial adsorbent materials, while simultaneously providing improved separation performance?

Project description During the laboratory scale, research-intensive phase of this project, several material types and morphologies were identified and explored. The outcome was three main types of adsorbents:

- Amines supported on hydrophobic periodic nanoporous materials (PNMs)
- Amine-grafted or -coated PNMs
- Amine-impregnated PNMs

Each class of materials exhibits the ability to adsorb CO_2 or water to various extents when exposed to dry or humid inlet gas with CO_2 contents at the parts per million level or higher. Further, extremely high single-pass capacities have been obtained: up to 1.5 times higher than the optimal uptake of 13X at 5% CO_2 feed, 1.0 atmosphere total pressure. The rate of adsorption on these materials is systematically higher than that of optimally regenerated 13X, the best observed maximum being 2.5 times as high as 13X zeolite.

Duration 2004–2005

Who is involved University of Ottawa [Org 5.1]

Funding level and funders $125,000 (2004–2005): NSERC

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Proj 8.4: CO_2 separation technology in combustion systems (UBC)

Goal To establish a facility to assess chemical looping combustion as an approach to providing a high-concentration CO_2 stream.

Question addressed Is the concept of utilizing metal oxide as an oxygen carrier to separate the flue gas streams in a combustion system feasible?

Project description Using a chemical looping combustion (CLC) unit, this project will examine the feasibility of a unique CLC reactor configuration that combines a fluidized bed process with the reduction–oxidation mechanism of metal oxides. (CLC is a process in which the air required for combustion never mixes with fuel. Instead, the O_2 is supplied by metal oxides that circulate between two separate air and fuel reactors.) This configuration produces a relatively high concentration of CO_2, which can be separated from other flue gas components and captured with relative ease, thereby reducing the cost of separation and increasing process efficiency.

Duration 2004–ongoing

Who is involved University of British Columbia [Org 5.6]

Funding level and funders $350,000: Canadian Foundation for Innovation, British Columbia Knowledge Development Foundation, NSERC

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Proj 8.5: Chemical looping combustion using CaO for CO_2 capture (CETC-O/UBC)

Goal To investigate the use of metal oxides as CO_2 sorbents in combustion processes.

Question addressed Can looping cycles based on metal oxides or carbonates be a more efficient and cost-effective way to capture CO_2?

Project description This project will define operating conditions for a looping cycle based on CaO and $CaCO_3$ in two linked fluidized beds. In the high-temperature bed, $CaCO_3$ will be introduced into an oxyfuel-fired combustion reactor, with the gas leaving the bed enriched in CO_2 from both the combustion process and the decomposition of the $CaCO_3$. In the second reactor, a lower temperature air-fired combustion reaction will allow the lime to combine with the CO_2 formed during combustion, stripping CO_2 from the combustion gas and generating $CaCO_3$ for recycle (looping) back to the first reactor. It is expected that this cycle will reduce by two thirds the oxygen demand of an oxyfuel cycle. The work will be conducted at two scales: in a 100 KW twin fluidized bed pilot unit and in a separate 1 MW twin bed unit—both located at the CANMET Energy Technology Centre–Ottawa. The work is divided into two principal areas: sorbent modification and improvement, and commissioning and operation of the pilot plant looping cycle combustors.

Duration 2003–2006

Who is involved CANMET Energy Technology Centre–Ottawa [Org 3.1] and the University of British Columbia [Org 5.6]

Funding level and funders $200,000: Natural Resources Canada (Program of Energy Research and Development) and NSERC

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Proj 8.6: Chemical looping combustion using Na_2CO_3 and $NaHCO_3$ for CO_2 capture (CETC-O and others)

Goal To investigate a looping cycle based on sodium carbonates as an alternative method of capturing CO_2 in combustion processes.

Question addressed Can looping cycles based on metal oxides and carbonates be a more efficient and cost-effective way to capture CO_2?

Project description This project will define operating conditions for a CO_2 looping cycle based on Na_2CO_3 and $NaHCO_3$ in two linked fluidized beds. In the first reactor, Na_2CO_3, CO_2, and H_2O combine to form $NaHCO_3$, separating the CO_2 from flue gas generated by a combustor. In a second reactor, the $NaHCO_3$ sorbent is heated, causing the release of CO_2 and H_2O. The Na_2CO_3 that is formed in the second reactor is then recycled to the first reactor. It is expected that this process will allow CO_2 to be captured from existing coal-fired power plants at a cost competitive with amine scrubbing. The work will be conducted at two scales: in a 100 KW twin fluidized bed pilot unit, and in a separate 1 MW twin bed unit, both located at the CANMET Energy Technology Centre–Ottawa.

Duration 2005–2007

Who is involved CANMET Energy Technology Centre–Ottawa [Org 3.1] and the Research Triangle Institute

Funding level and funders $550,000: Natural Resources Canada and the Research Triangle Institute

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Proj 8.7: Enzyme-catalyzed capture of CO_2 in carbonates (CO_2 Solution)

Goal To demonstrate a novel process for capturing CO_2 in flue gas streams using an enzyme bioreactor with subsequent sequestration in the form of inert bicarbonate compounds.

Question addressed Is it technically feasible to use the catalytic action of an enzyme to capture CO_2 in flue gas streams?

Project description This project seeks to demonstrate a novel technology for capturing CO_2 in flue gas from various industrial streams such as aluminum foundries, incinerators, and so on. The technology consists of an enzyme bioreactor designed to operate in an aqueous environment. The bioreactor captures the CO_2 and converts it into inert bicarbonate compounds. The aqueous solution is then regenerated in an ion-exchange column and recycled to the bioreactor. The presence of enzyme accelerates the absorption of CO_2 by converting it into carbonate and bicarbonate ions. The ions are subsequently precipitated during the regeneration process of the ion exchange column. The technology was successfully demonstrated at the pilot scale at an aluminum refinery. The industrial-scale demonstration is proceeding at a municipal incinerator.

Duration 2002–2005

Who is involved CO_2 Solution Inc.

Funding level and funders Total cost not disclosed: Sustainable Development Technology Canada and consortium members—L'agence de l'efficacite energetique; Aluminum Association of Canada, Centre intégré de fonderie et de métallurgie (CIFM); Elkem Metal Canada; Federation of Canadian Municipalities (Green Municipal Investment Fund); Fonderie industrielle Laforo Inc.; Place Bonaventure; Ville de Québec

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Proj 8.8: Production of hydrogen and carbon monoxide from CO_2 reforming of methane (Saskatchewan)

Goal To create a technology that captures CO_2 and that produces H_2 and CO.

Question addressed Can you capture CO_2 and, through methane reforming, produce a value-added energy stream (H_2 and CO), while reducing overall CO_2 emissions?

Project description This project will focus on the development of a technology that captures CO_2 via adsorption and that produces H_2 and CO by reforming CH_4 with CO_2. The project includes these steps:

1. Investigation of preparation methods for CO_2 adsorbents with high selectivity and large capacity, and reforming catalysts with high activity and long-term stability.
2. Studies of the process that combines CO_2 adsorption and regeneration (using a CH_4 stream) to produce the raw gas for reforming.
3. Development of the reaction mechanism and kinetics of catalytic reforming of CH_4 with CO_2 and of the reactor design.
4. Scaling-up of the adsorbent and catalyst production, the adsorption–regeneration process, and the reforming reaction.

The energy that this catalytic reaction process needs can be provided by waste-heat sources, such as the high-temperature stack gas from combustion boilers.

Duration 2003–2007

Who is involved University of Saskatchewan [Org 5.1]

Funding level and funders $18,000 annually for each of four years: NSERC

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Proj 8.9: Direct carbon fuel cells (CETC-O and others)

Goal To generate experimental data needed for designing direct carbon fuel cells (DCFC) by building a small experimental unit and testing the performance of direct carbon conversion in catalytically activated molten carbonate mixtures.

Question addressed Can direct carbon fuel cells provide an efficient and clean alternative to combustion of carbon-based fuels?

Project description A small (approximately 10 W) DCFC will be designed, constructed, and tested. DCFC performance will be examined using commercially useful carbon feeds: coal-derived carbon (high-ash carbon), petroleum coke (high-sulphur carbon), and natural gas-derived carbon (clean carbon). Tests will reveal the effect of impurities such as ash and sulphur on carbon conversion. DCFC development will utilize much of the work done to date on molten carbonate fuel cells. A DCFC would produce electrical power at high conversion efficiency and with a pure CO_2 waste stream suitable for storage.

Duration 2005–2008

Who is involved CANMET Energy Technology Centre–Ottawa (CETC-O), Natural Resources Canada [Org 3.1], and GenCell Technologies (Connecticut)

Funding Level and Funders $450,000 total: Natural Resources Canada (Climate Change Technology and Innovation via CETC-O's Clean Coal CO_2 Capture and Storage Strategy, Program of Energy Research and Development, and A-Base), GenCell Technologies

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Proj 8.10: Development of zero emissions direct ammonia fuel cells for efficient combined heat and power (CETC-O and others)

Goal To develop a zero emissions solid electrolyte fuel cell that operates directly on ammonia.

Question addressed Can ammonia fuel cells facilitate low-CO_2 power production cycles?

Project description This project will build on earlier work to develop a solid electrolyte fuel cell that utilizes ammonia directly as a carbon-free fuel source. The novel fuel cell converts ammonia to H_2 and N_2, and protons are the active charge carriers. H_2O at the cathode and N_2 at the anode are the only chemical products of the fuel cell.

This project will focus on accelerating the development and eventual deployment of ammonia fuel for applications in decentralized electricity production and combined heat and power. Ammonia can be produced from natural gas or coal or as a byproduct of oil sands upgrading. The process yields a high-purity CO_2 waste stream. This project includes marketing studies, an early field trial using a conventional fuel cell running on ammonia (in a combined heat and power (CHP) or ammonia refrigeration application), fuel cell performance testing (lab scale), and materials development and compatibility assessments.

Duration 2005–2008

Who is involved CANMET Energy Technology Centre–Ottawa (CETC-O) [Org 3.1], with CANMET Materials Technology Centre, National Research Council Institute for Chemical Processing and Environmental Technology [Org 3.4], and Terra International

Funding level and funders $2.1 million total: $1.8 million from Natural Resources Canada (Climate Change Technology and Innovation via CETC-O's Clean Coal CO_2 Capture and Storage Strategy, Program of Energy Research and Development, and A-Base), and $300,000 from Terra Industries

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Proj 8.11: Activation of CO_2 for recycling and abatement (Ottawa)

Goal To expand knowledge of CO_2 chemistry for the development of catalytic cycles for the formation of C–C bonds starting from CO_2.

Question addressed Can a simple catalytic cycle analogous to photosynthesis be employed to sequester CO_2?

Project description This project will develop fundamental knowledge in the field of the organometallic chemistry of CO_2 aimed at discovering catalytic processes for CO_2 abatement and recycling. In particular, stoichiometric reactions leading to the formation of oxalates will be sought. The model systems provided by these reactions will enable the factors that favour or disfavour study of CO_2 reductive coupling. This phase of the project will require preparation of transition metal complexes of sufficient reducing power to perform fixation and reduction of CO_2. Once all the necessary information to enable these transformations is obtained (nature of the metal, electronic configuration, nature of the ligand), the second phase of the project, preparation of the transformation catalyst, will start.

Duration 2003–2007

Who is involved University of Ottawa [Org 5.1]

Funding level and funders $92,000 (2003–2004); $92,000 (2004–2005); $92,000 (2005–2006): NSERC

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Proj 8.12: Advanced greenhouse gas mitigation based on hydrates (UBC)

Goal To provide basic thermodynamic and kinetic data for the conceptual design of CO_2 separation processes based on hydrate crystallization.

Question addressed Can gas hydrates be used to separate CO_2 from flue gases?

Project description Gas hydrate crystallization offers an opportunity for the development of innovative technology for CO_2 separation from CO_2 and N_2 or flue gases ("post-combustion capture"). Moreover, carbon may be removed before combustion through the separation of CO_2 from mixtures of CO_2 and H_2 in integrated gasification, combined-cycle power plants ("pre-combustion capture"). The idea is that the concentration in the hydrate crystals is different than that in the gaseous mixtures, creating a basis for the separation. The project addresses these issues:

- The composition of the hydrate crystals formed from mixtures of CO_2 and N_2 (flue gas) and of CO_2 and H_2
- The rate of hydrate crystal formation and decomposition from mixtures of CO_2 and N_2 and of CO_2 and H_2
- The best mode of contact of the gas phase with water to form hydrate crystals (Is the mode scaleable for industrial application?)

Duration 2003–2006

Who is involved University of British Columbia [Org 5.6]

Funding level and funders $77,500 (2003–2004); $82,500 (2004–2005): NSERC

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Proj 8.13: Hydrate technology for gas separation and CO_2 capture (NRC/UBC)

Goal To develop a new approach to gas separation, especially to use hydrate technology to capture CO_2 from flue gas.

Question addressed Can CO_2 be effectively separated from flue gas by formation of hydrates?

Project description This work complements that of Proj 8.12. A laboratory facility will be established to serve as a template for scaling up the process based on hydrate formation in water dispersed in a porous medium. Earlier work showed that, on a small scale, the use of hydrate formation to separate CO_2 from flue gas is quite efficient, with drastically improved kinetics of hydrate formation.

The major portion of the work is in the design, fabrication, setting up, and testing of the equipment. Optimum operating conditions will be chosen based on previous thermodynamic work, but the operating mode of the facility (semi-batch or batch) and the scale of the process (flow rate of CO_2) based on emissions from a typical power plant have yet to be determined. A model flue gas mixture (17% CO_2, balance N_2) will be chosen for the work.

Duration 2006–2008

Who is involved National Research Council [Org 3.4] and the University of British Columbia [Org 5.6]

Funding level and funders $406,000: CANMET Energy Technology Centre–Ottawa (Natural Resources Canada—Climate Change Technology and Innovation), National Research Council, University of British Columbia, and an industrial partner not yet named

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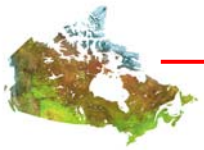

9. TRANSPORT

Proj 9.1 Integrated Carbon Dioxide Network (ICO_2N)

Goal To establish a system that would enable CO_2 to be moved between sources and sinks.

Question addressed How can the commercial potential of a CO_2 market be realized?

Project description Five lead companies have collaborated to establish the system and infrastructure needed for the sale, transport, and purchase of CO_2. The project is described as national in scope and is setting out to design and create infrastructure that will serve long-term needs—not just to build a pipeline linking current sources with near-term EOR applications. The project will help establish the partnerships, tariffs, incentives, and regulations required to make a CO_2 market successful. The goal is to be moving 20 megatonnes of CO_2 annually by 2020.

Duration 2006–ongoing

Who is involved Tier 1: Suncor [Org 8.3], Air Products, Husky, Nexen, Shell; Tier 2: Canadian Natural Resources Ltd., Agrium, Conoco Phillips, Syncrude, TransAlta [Org 8.14], Imperial Oil; ENGOs: Pembina Institute [Org 6.1]

Funding level and funders Not available

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10. STORAGE—GENERAL

Proj 10.1: Acid-gas re-injection in Alberta and British Columbia (AGS/ARC)

Goal To draw from Canadian experience with acid-gas re-injection to gain an understanding of CO_2 sequestration behavior.

Question addressed What is the fate of CO_2 when injected into geological formations?

Project description Acid-gas injection operations in western Canada represent a commercial-scale analogue for geological sequestration of CO_2. Thus, study of acid-gas injection operations provides an opportunity to learn about the safety of these operations and about the fate of the injected gases and to investigate the feasibility of CO_2 geological storage.

Currently, acid gas is injected into depleted oil and gas reservoirs and deep saline aquifers at 52 operations in Alberta and British Columbia. The composition of the injected gas varies from 2% H_2S and 98% CO_2 to 84% H_2S and 14% CO_2. The information submitted by operators to regulatory agencies in Alberta and British Columbia and information obtained from additional sources is being used to produce a comprehensive hydrogeological characterization of these operations by cluster, with the objective of selecting a monitoring site for better understanding the fate of the injected acid gas. In addition, one site underwent a comprehensive due diligence process to establish the viability and importance of this technology for creating GHG emission credits when a trading market is firmly established.

Duration 2001–2006

Who is involved Alberta Geological Survey of the Alberta Energy and Utilities Board [Org 4.3] and the Alberta Research Council [Org 4.2]

Funding level and funders $205,000 for Phases I and II; $800,000 for Phase III: Canadian federal and provincial governments and government agencies, the International Energy Agency Greenhouse Gas R&D Programme, and industry participants

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Proj 10.2: Analysis of acid-gas injection sites in Alberta that have experienced unforeseen reservoir performance problems (AGS and others)

Goal To understand the fate and impact of injected acid gas in a variety of operational and geological conditions, and to evaluate the potential for migration and leakage from the injection target.

Question addressed What can unforeseen injection problems say about the way reservoir performance is modelled and predicted before CO_2 injection?

Project description This project follows on from Proj 10.1. It will examine unforeseen operational problems have been experienced at five Alberta acid-gas injection sites, none of which is being studied under the current program. These in situ operational problems are either breakthrough of acid-gas at a producing well or early overpressuring of the reservoir. They show that the injection reservoirs were not necessarily properly characterized or that the effect of injection on the reservoir was different than predicted. The proposed project will conduct an analysis to

- identify the causes of the unexpected in situ operational problems.
- examine the information on which the predictions of reservoir behaviour were based.
- compare the resulting information with the currently available information and with information that will be produced by the project, to identify the possible causes of the original interpretation and prediction of reservoir behaviour.
- identify information that normally is not required and that should be used in the future in the selection and evaluation of potential sites for the injection and storage of greenhouse and acid gaes.

To achieve these goals, lab experiments and testing will be conducted on core samples for mineralogy, permeability and porosity, and relative permeability. Data will be collected from wells in the respective areas, and thermodynamic and numerical models will be applied to predict the behaviour of the in situ fluids and injected gas.

Duration 2006–2008

Who is involved Alberta Geological Survey (Alberta Energy and Utilities Board [AEUB]) [Org 4.3], University of Calgary [Org 5.2], Fekete Engineering, oil and gas companies

Funding level and funders $660,000: CANMET Energy Technology Centre–Ottawa (Natural Resources Canada—Climate Change Technology and Innovation), AEUB, Fekete Engineering, University of Calgary, industrial operators

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Proj 10.3: Regional-scale mapping of in situ stresses and rock mechanical properties in the Alberta basin for CO_2 geological storage (Saskatchewan)

Goal To map minimum in situ stress magnitudes and rock mechanical properties in the Alberta Basin, for use in the selection and preliminary design of CO_2 geological storage sites.

Question addressed To avoid hydraulic fracturing and consequent leakage, what are the upper limits on CO_2 injection pressures?

Project description Phase 1 of this project involved the interpretation of minimum in situ stress magnitudes from an existing database of more than 1400 measurements made in the Alberta Basin. The database included fracture closure pressures from mini- and micro-frac tests, leak-off pressures measured during drilling operations, and fracture breakdown pressures measured during hydraulic fracture stimulation treatments.

Minimum horizontal stress gradients in the 16 to 18 kPa/m range were interpreted for much of the Alberta Basin from tests conducted over depths from approximately 250 m to approximately 1000 m in non-reservoir rocks. The limited leak-off pressures available for depths greater than 1000 m are consistent with a proposed minimum horizontal stress gradient of 17 kPa/m or slightly greater in rocks that have not been affected by production. Minimum horizontal stress gradients estimated for depths between approximately 1000 and 3000 m in the southwest and west-central portion of the Basin were generally close to 13 kPa/m. The stresses in these reservoir rocks are believed to be affected by pressure depletion. Minimum horizontal stress gradients up to 19 kPa/m have been estimated for the northern portion of the basin.

Work currently underway in Phase 2 of this project involves the regional-scale mapping of rock mechanical properties for selected potential storage reservoirs and their caprocks. This work will be done using wireline geophysical logs, calibrated to laboratory-measured rock mechanical properties compiled in an Alberta Geological Survey database.

Duration 2004–2006

Who is involved University of Saskatchewan [Org 5.1]

Funding level and funders $31,000: Alberta Energy and Utilities Board (Alberta Geological Survey)

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Proj 10.4: Nova Scotia CO_2 storage demonstration project (Dalhousie/NSPI)

Goal To assess the basins of Nova Scotia to identify a suitable site for a demonstration project to test the feasibility of geological carbon storage in Atlantic Canada, and to design, build, and run a 100 kilotonne pilot project to demonstrate commercial viability.

Question addressed Is CO_2 storage a viable approach for Atlantic Canada's GHG emissions reduction strategy?

Project description Phase 1 of the project (years 1–5) will focus on geological and geographic analysis of the region. During the early stages of the investigation (year 1), a group of geographic and geological areas (subsurface prospects) will be ranked in terms of their feasibility as carbon storage sites. During the later stages of the investigation, a battery of existing and novel field and laboratory techniques will be used to fully evaluate the top-ranked site. The later stage of the geological analysis (years 2 through 5) will operate in conjunction with Phase 2, the establishment of a pilot demonstration project, during which the CO_2 storage capability of the selected site will be tested and CO_2 retention will be monitored.

Throughout the investigation, the Carbon Storage Research Consortium (CSRC) will conduct concurrent research into public awareness and perception of CO_2 capture, transmission, and storage; public policy and regulatory issues; economic impacts of CO_2 storage; engineering risk analysis; and verification and monitoring of stored CO_2.

Duration Phase 1: 2006–2011; Phase 2: 2007–?

Who is involved CSRC: An industry/academic partnership led by Dalhousie University and Nova Scotia Power Inc.

Funding level and funders Phase 1—approximately $4.5 million: Atlantic Canada Opportunities Agency (proposed), Nova Scotia Power Inc. (committed), Schlumberger Information Solutions (in-kind)

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Proj 10.5: Geologic sequestration of CO_2 and simultaneous CO_2 sequestration and CH_4 production from natural gas hydrate reservoirs (GSC)

Goal To assess the feasibility of storing large amounts of CO_2 in gas hydrates in Canada and of possible coincident methane production from existing natural gas hydrate reservoirs.

Question addressed Does CO_2 gas hydrate offer an attractive means of storing CO_2 while providing an offsetting revenue stream?

Project description Theory and limited laboratory data suggest that excess CO_2, when introduced into a methane hydrate reservoir, may displace CH_4 in favour of the formation of stable CO_2 hydrate. This project assesses the feasibility of geologic sequestration of CO_2 as a gas hydrate and the possibility of coincident CO_2 sequestration with CH_4 production from natural gas hydrate reservoirs such as those occurring off Canada's coasts, in the Great Lakes, or in the Arctic. Given the intrinsic efficiency of CO_2 storage within the clathrate structure, a huge sequestration potential may exist in close proximity to point-source emissions in western and eastern Canada.

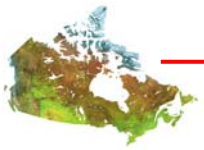
The project will

- conduct a program of fundamental laboratory research to establish the porous media controls on CO_2 hydrate formation in geologic media and to investigate the thermodynamic conditions favouring the displacement of CH_4 from methane hydrate by CO_2.
- in conjunction with drilling of the 2002 Mallik International Gas Hydrate Production Research Well, conduct field investigations of the physical, geothermal, and geochemical characteristics of an existing gas hydrate-bearing reservoir.
- using archived geological data, identify and characterize a suite of candidate marine, lacustrine, and Arctic reservoirs.
- assess the feasibility of geological sequestration of CO_2 as gas hydrate, with respect to both terrestrial and subaquatic reservoirs in Canada.
- evaluate the feasibility of co-production of CH_4 gas in conjunction with CO_2 injection in existing natural gas hydrate reservoirs.

Duration 2001–2005

Who is involved Geological Survey of Canada (Natural Resources Canada) [Org 3.3], National Research Council [Org 3.4], University of Ottawa [Org 5.1], Mallik 2002 International Gas Hydrate Production Research Well Consortium

Funding level and funders More than $1 million: Climate Change Action Plan (Natural Resources Canada) and Mallik Consortium (in kind)



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11. STORAGE—EOR/EGR

Proj 11.1: Hydrogeology of the Weyburn CO_2 Project for prediction of CO_2 sequestration performance (Alberta)

Goal To characterize the groundwater flow patterns in and around the Weyburn oil field to allow predictions of CO_2 migration following injection for EOR and CO_2 sequestration.

Question addressed What is the "plumbing" in and around the Weyburn CO_2 injection site, and how does it affect storage capacity for CO_2?

Project description This project is part of a PhD thesis. It will use data from deep drilling, seismic reflection surveys, and geological mapping to establish a detailed hydrostratigraphic framework. Hydrogeological data will subsequently be assigned to the appropriate aquifers in the hydrostratigraphic section. Extensive processing of the raw data to remove non-representative data, and application of specialized techniques to quantify density-dependent flow of subsurface brines, will provide a detailed characterization of the formation–water flow regime within a sizeable portion of the Williston Basin, centered on the Weyburn oilfield. Geostatistical techniques will be used togenerate models of spatial permeability variations within key aquifers for input to the Weyburn Project risk assessment model. The ultimate deliverable is a three-dimensional characterization of formation–water flow patterns within the study area.

Duration 2004–2005

Who is involved University of Alberta [Org 5.8]

Funding level and funders 21,000 (2004–2005): NSERC

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Proj 11.2: Anadarko's Hayes EOR demonstration

Goal To demonstrate that CO_2 captured from a gas plant can be used to increase oil recovery, and to develop a better understanding of the economics involved.

Question addressed How effective is CO_2 injection for EOR and CO_2 storage in the Hays reservoir?

Project description Anadarko Canada Corporation will capture the CO_2 currently being vented from its Hays gas plant for injection into the Enchant Arcs reservoir. The company plans to inject CO_2 into five existing wells of the reservoir.

Duration 2004–2008

Who is involved Anadarko Canada Corporation [Org 8.4]

Funding level and funders Funded in part by Natural Resources Canada under the CO_2 Capture and Storage Incentive program, and by the Alberta Department of Energy under the CO_2 Projects Royalty Credit Program

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Proj 11.3: Apache's Zama EOR demonstration

Goal To test the use of acid gas in a "top-down" EOR project both for oil recovery and CO_2 storage.

Question addressed Can acid gas be used effectively instead of CO_2?

Project description The Zama Acid Gas EOR Project has reconfigured the Zama gas plant to cease sulphur plant operations. The CO_2 and H_2S effluent was previously being converted to sulphur or vented and is now being disposed of by injection as an EOR solvent.

Apache Canada Ltd. plans to convert four depleted Keg River pinnacles into "top-down" acid-gas EOR projects. The top-down technique, which has not previously been used for EOR, means that the acid gas will be injected into the top of the pinnacle, with incremental oil being produced from a separate well located in the bottom of the pinnacle. Subsequent breakthrough of acid-gas solvent will be recycled into the additional candidate pinnacles in the area. Once all the incremental oil has been recovered from a pinnacle, that pinnacle will be used for acid-gas disposal and sequestration. The initial acid-gas supply should be adequate to begin flooding of the first two pinnacles.

Duration First injection, December 2004. Project will continue indefinitely and is limited only by the volume of acid gas available for injection.

Who is involved Apache Canada Limited [Org 8.2]

Funding level and funders Approximately $22.5 million: Apache Canada Ltd., Natural Resources Canada (the CO_2 Capture and Storage Incentive program), and Alberta Department of Energy (the CO_2 Projects Royalty Credit program)

Contact

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Proj 11.4: Penn West's Pembina EOR demonstration

Goal To determine the economic viability of CO_2 EOR as a tertiary recovery process for a significant portion of the Pembina Cardium oil pool.

Question addressed Will CO_2 EOR be cost-effective in the Pembina field, and can an ultimate CO_2 storage capacity of 100 Mt be realized?

Project description Penn West Energy Trust has drilled two new wells in part of its Pembina Cardium lands for use as CO_2 injection wells. During the two-year injection process, and for one to three years thereafter, six offset wells will be produced to test EOR and CO_2 storage. The Pembina Cardium pool is the largest conventional light oil pool ever discovered in Canada, with significant potential for tertiary EOR and CO_2 storage capacity.

Duration 2004–2008

Who is involved Penn West Energy Trust [Org 8.5]

Funding level and funders Approximately $20 million: Funded in part by the CCS Incentive Program (Natural Resources Canada) and the CO_2 Projects Royalties Credit Program (Alberta Department of Energy)

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Proj 11.5: Devon Canada, Swan Hills CO_2 EOR demonstration

Goal To confirm ability to safely inject CO_2, to evaluate incremental hydrocarbon recovery, and to evaluate amount of CO_2 sequestered.

Question addressed Is CO_2 capture and storage in oil reservoirs commercially viable and reliable?

Project description Devon Canada Corporation is currently injecting CO_2 into one injection well and is monitoring production from offset wells, including five directly offsetting producing wells. Injection began in October 2004 and is scheduled to proceed for eighteen months. The offset producing wells will continue to be monitored beyond the last injection date, as required, to meet the goals indicated. The scope of the project includes reconfiguring the injection and direct offset producing wells. A temporary CO_2 injection facility and a new permanent satellite production test facility will be installed.

Duration Injection: October 2004–First quarter 2006; Monitoring: Until end 2006

Who is involved Devon Canada [Org 8.6]

Funding level and funders Cost not disclosed. Funded in part by Alberta Energy's CO_2 Projects Royalty Credit Program and Natural Resources Canada's Carbon Dioxide Capture and Storage Incentive Program

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Proj 11.6: Effect of residual O_2 in CO_2 for a combined miscible flood and CO_2 sequestration process (Calgary)

Goal To determine how much tolerance there is for O_2 as an impurity in CO_2 streams used in EOR and sequestration processes.

Question addressed Can the costs of CO_2 capture be reduced by allowing significant amounts of O_2 to remain with the CO_2 stream?

Project description Capturing the CO_2 from stack gases is an expensive process and the actual cost depends on the purity of the CO_2 stream required. O_2 is an important impurity, because it can modify the native oil properties through low-temperature oxidation reactions, promote corrosion in the injection and production piping, and alter the phase behavior of the reservoir fluids. This study will examine how O_2 is consumed in the reservoir and will concentrate on the impact of oxidation reactions with regard to the composition and emulsification characteristics of the oil and the pH levels of the connate water.

Duration 2003–2007

Who is involved University of Calgary [Org 5.2]

Funding level and funders $100,000: Alberta Energy Research Institute

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Proj 11.7: Effect of oil and flue-gas composition on oil recovery in the flue-gas and light oil injection process (Calgary)

Goal To determine the effect of the composition of a flue gas (N_2, O_2, SO_x, etc.) and of the oil composition on combined EOR and CO_2 sequestration processes.

Question addressed How effective is flue gas as an EOR injectant, and how pure does the CO_2 need to be for use in EOR and sequestration?

Project description This project investigates the impact on oil recovery and on CO_2 storage of the composition of flue gas with particular attention to the CO_2 content of the injection stream and the composition of the oil in the reservoir. Core flood and high-pressure pressure–volume–temperature experiments were both employed.

Duration 2003–ongoing

Who is involved University of Calgary [Org 5.2]

Funding level and funders Not disclosed: NSERC and industry partners

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Proj 11.8: Studies of CO_2 utilization and extraction (PTRC/SRC)

Goal To optimize use of CO_2 in EOR and to extend CO_2 EOR to heavier oil reservoirs.

Question addressed How can CO_2 EOR practice be improved and extended to heavier oils?

Project description This project will develop technologies to promote the storage of CO_2 (pure or extracted from waste flue gas) through its use as an EOR agent. Prime objectives are these:

- to improve the performance and economics of CO_2 floods.
- to extend the applicability of CO_2 injection from light and medium oil reservoirs (such as Weyburn) to fields containing heavier oils, thus expanding the potential sources of CO_2.

This project will address several areas in which technology gaps exist—for example:

- application of cyclic gas injection ("huff'n'puff") to water-flooded oil reservoirs.
- immiscible CO_2 and flue gas injection in thin heavy oil reservoirs (most of Saskatchewan's reservoirs).
- optimization of gels and gel placement techniques to control CO_2 conformance, improving sweep efficiency and thus expanding reservoir storage volume.
- identification of mechanisms of CO_2 oil recovery enhancement and sequestration formation of clathrate hydrates to isolate CO_2 from flue gas.

Duration March 2002–April 2007

Who is involved Petroleum Technology Research Centre [Org 4.6] and Saskatchewan Research Council [Org 4.5]

Funding level and funders $500,000: Industry participants, Petroleum Technology Research Centre, Saskatchewan Research Council

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Proj 11.9: Enhancing the capacity of CO_2 storage by removing the remaining water in depleted oil reservoirs (Regina)

Goal To develop strategies to maximize the CO_2 storage capacity of depleted oil reservoirs.

Question addressed How should CO_2 be injected into various reservoirs to achieve maximum storage?

Project description The objective of this proposal is to develop CO_2 storage injection techniques for efficiently displacing and producing the water retained in reservoirs after an EOR process, thus enhancing the CO_2 storage capacity of the reservoirs. Depleted oil reservoirs with varying conditions and oil production histories will be investigated for CO_2 storage injection. The techniques for efficiently displacing and producing the retained water after an EOR process will be investigated for varying oil reservoir types (water wet, oil wet, sandstone, carbonate, and fractured) under varying production histories (water flooding plus chemical EOR, and waterflooding plus CO_2 EOR). Laboratory tests using the respective reservoir cores will be carried out to study different CO_2 injection and water production processes, and to obtain the input data required in reservoir simulation for optimizing the CO_2 storage capacity for various reservoirs. Field-scale reservoir simulations will be conducted to investigate the capacities of CO_2 storage for various CO_2 injection and water production schemes under various reservoir conditions. The experimental and numerical simulation results will be integrated to generate guidelines for CO_2 storage injection under various reservoir conditions to achieve the maximum capacity for actual oil reservoirs.

Duration 2004–2008

Who is involved University of Regina [Org 5.3]

Funding level and funders $268,500: Natural Resources Canada (Climate Change Technology and Innovation via the CANMET Energy Technology Centre–Ottawa Clean Coal CO_2 Capture and Storage Strategy), NSERC, University of Regina, Petroleum Technology Research Centre

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Proj 11.10: Optimizing CO_2 storage in oil reservoirs (ARC)

Goal To investigate CO_2 injection factors that contribute to maximization of geological storage of CO_2, while also inducing incremental recovery of oil by EOR techniques.

Question addressed What changes to EOR practice should be made to emphasize CO_2 storage rather than oil recovery?

Project description This project will examine the complete oil reservoir development cycle in stages, with the purpose of maximizing CO_2 storage in reservoirs. The range of reservoir types examined will span conventional sandstone and carbonate light oil reservoirs typically found in the Western Canadian Sedimentary Basin. A reservoir simulation model will be used to establish baseline scenarios for various Alberta CO_2 EOR candidate reservoirs operated in the traditional manner (primary recovery, followed by water flood, and then CO_2 flood) with realistic field performance. Two to three reservoirs will be chosen based on reservoir characteristics to represent a wide range of candidates for CO_2 EOR. After the baseline scenario has been established for a given reservoir, detailed simulation and economic studies will be conducted to investigate the effects of different CO_2 EOR operating strategies on the CO_2 EOR performance and CO_2 storage capacity.

Duration 2004–2008

Who is involved Alberta Research Council [Org 4.2]

Funding level and funders $690,000; Natural Resources Canada, Alberta Research Council, Schlumberger and Computer Modelling Group, Penn West Petroleum and the Alberta Energy Research Institute (proposed)

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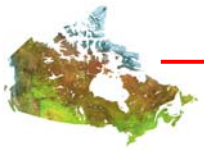

12. STORAGE—ECBM

Proj 12.1: Sedimentology, diagenesis, gas sorption characteristics, and sequestration potential of organic-rich rocks (UBC)

Goal To establish factors that affect the distribution, abundance, and composition of organic matter in sedimentary rocks to determine the potential for production and storage by sorption of gas in organic-rich strata (coal and oil shales).

Question addressed How can you determine the CO_2 storage capacity of coal and oil shale deposits?

Project description This project will

- study the sedimentology of peat deposits and modern organic-rich sediments from various parts of the world.
- conduct laboratory studies to quantify the effects of pressure, temperature, and stress and strain on diagenesis, fabric, permeability, and diffusion rates of gas in this organic matter.
- evaluate the gas storage capacity and content of black shales in the Western Canadian Sedimentary and Williston basins, including evaluation of the resources and factors that affect gas capacity, content, and sequestration potential of CO_2 (and other gases such as H_2S and oxides of sulphur and nitrogen).
- develop analytical protocols for characterizing the light elements (C, O, N) in macerals by electron microprobe and functional groups by micro–Fourier transform infrared spectroscopy.
- assess fundamental controls on gas sorption capacity and on potential for sequestration of CO_2 and other acid gases by coal and shales.

Duration 2000–2005

Who is involved University of British Columbia [Org 5.6]

Funding level and funders $86,625 (2000–2001); $86,625 (2001–2002); $88,560 (2002–2003); $88,560 (2003–2004); $88,560 (2004–2005): NSERC

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Proj 12.2: CO_2 disposal in coalbed methane reservoirs (Alberta)

Goal To understand the geotechnical behavior of deep coalbed methane (CBM) reservoirs for the application of CO_2 disposal and the simultaneous recovery of coalbed methane.

Question addressed How do coalbeds respond to the changing conditions associated with CBM, and how will these responses affect CO_2 storage and CH_4 recovery?

Project description This project encompassed several fundamental research aspects:

- A careful review of the literature to identify the extent and value of existing data on CBM as it pertains to CO_2 sequestration.
- Laboratory testing of reconstituted and intact core specimens of coal. Initial testing was carried out under one-dimensional boundary conditions. These fundamental experiments were aimed at providing measurements on the volume change (swelling or consolidation) and subsequent permeability variations within the coal to CO_2 adsorption and CH_4 desorption. The second stage of laboratory testing focused on increasingly realistic boundary conditions and coal specimen quality. Drained and undrained triaxial tests of intact core specimens examined issues such as stress-path effects and matrix (and possibly fracture) permeability variations.
- The testing mentioned above provided the constitutive parameters necessary for geomechanical modelling studies. This aspect involved identification of the geomechanical processes involved in CBM recovery in the Western Sedimentary Basin and development of a geomechanical model of the CBM process relative to CO_2 sequestration. The primary focus was reservoir–geomechanical modelling of the CO_2 sequestration process. The controlling geomechanical physics and their interaction with reservoir processes were identified. Available data from field tests such as minifrac, geophysical log interpretations, and production and injection data were incorporated into this phase of the research.

Duration 1998–2004

Who is involved University of Alberta [Org 5.8]

Funding level and funders $24,833 annually for each of six years: NSERC

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Proj 12.3: Coalbed methane and enhanced coalbed methane reservoir characterization methodology (Alberta)

Goal To develop a methodology to categorize coal seams, with the goal of understanding, identifying, and quantifying the key hydromechanical properties controlling primary and enhanced methane recovery and geological CO_2 sequestration in coalbeds.

Question addressed How can simulations of CO_2 injection into coalbeds be improved?

Project description The project is composed of two principal streams: understanding permeability behaviour during production of methane and injection of CO_2, and determination of critical geological identifiers needed for upscaling the hydromechanical properties of coal to a continuum model for use in simulations. The following tasks are planned:

- Modify the isothermal, multiphase fluid flow, isotropic stress-state facility to enable testing under *in situ* conditions.
- Establish the relationship between the coal fracture networks, permeability, and *in situ* stresses and stress changes for Western Canadian Sedimentary Basin (WCSB) coals.
- Develop numerical and geostatistical methodologies to upscale from discontinuum to a continuum.
- Establish the influence of CH_4 and CO_2 sorption on the hydromechanical constitutive behaviour of coals at *in situ* conditions.
- Integrate information from experimental results and observed field data into a methodology for coalbed reservoir characterization.
- Modify sequentially coupled reservoir–geomechanical simulations to include experimentally observed *in situ* behaviour of WCSB coals.
- Select suitable sites to verify predictability of developed reservoir characterization and reservoir geomechanical simulation methodologies and tools.
- Conduct performance assessment studies for two or three generic enhanced coalbed methane (ECBM) project scenarios.

Duration 2005–2008

Who is involved University of Alberta [Org 5.8]

Funding level and funders $304,000: CANMET Energy Technology Centre–Ottawa (Natural Resources Canada–Climate Change Technology and Innovation), Alberta Energy Research Institute, Alberta Research Council, NSERC

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Proj 12.4: Enhanced coalbed methane and CO_2 storage piloting in Qinshui Basin, Shanxi Province, China (ARC and others)

Goal To test the viability of storing CO_2 in deep unmineable coalbeds and of using CO_2 injection for enhanced coalbed methane (ECBM) recovery.

Question addressed Are coal seams in this part of China permeable and stable enough to absorb CO_2 and enhance methane production?

Project description China is rich in both coal and CBM resources. China is the world's largest coal producer and consumer, and one of the largest sources of GHG emissions. This project promotes environmentally sustainable development in China through the transfer of Canadian CBM and CO_2 storage technology to effectively exploit CBM while storing CO_2 in unmineable deep coalbeds.

A single-well micro-pilot test was carried out in the anthracitic coals of the Qinshui Basin from late 2003 until mid-2004. The data and information collected are still under analysis, but the results are very promising. Hopefully, those results will lead to the successful implementation of a field pilot.

Duration 2002–2005

Who is involved Alberta Research Council [Org 4.2], Sproule International Ltd., the Computer Modelling Group [Org 8.11], Computalog, CalFrac, SNC Lavalin, and Porteous Engineering ("Canadian ECBM Consortium"), with China United Coalbed Methane Company Ltd.

Funding level and funders $10 million: $5 million from the Canadian International Development Agency under the Canadian Climate Change Development Fund (CCCDF), $5 million from Ministry of Commerce in China through the China Coalbed Methane Company

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Proj 12.5: Carbon Sequestration and Enhanced Methane Production (CSEMP) (Suncor and others)

Goal To inject and sequester CO_2 into a subsurface coal reservoir so as to enhance the production of coalbed methane (CBM) while storing the CO_2 in the same reservoir.

Question addressed Is it technically and economically feasible to use CO_2 to enhance CBM production while using the same coal seams to sequester CO_2?

Project description This project will test carbon sequestration and enhanced CH_4 production in a closed-cycle pilot project. The CO_2 will be injected and sequestered in a subsurface coal reservoir, and the effect on produced volumes of CBM that results will be determined. Suncor Energy Inc., on behalf of its partners, is conducting a pilot project 20 kilometres south of Drayton Valley, Alberta, where CO_2 will be injected into a well between two closely spaced CBM production wells. The project is intended to test for increased CH_4 production from Alberta coal seams by CO_2 injection and to determine the parameters of CO_2 storage and potential enhanced methane production from the coal.

The original site selected turned out to be unfeasible for CO_2 injection, and the well was abandoned. A new site at an existing CMB production field has been identified based on improved reservoir characteristics. The project is ready to commence injection, pending receipt of certain environmental permits from the provincial government. Preliminary results are expected in 2006. This project is part of Canada's contribution to the Carbon Sequestration Leadership Forum.

Duration 2002–2008

Who is involved Suncor Energy Inc. [Org 8.3], EnCana Corporation [Org 8.5], MGV Energy Inc., TransCanada Pipelines Ltd., Enerplus Resources, Penn West Petroleum Ltd. [Org 8.1], Air Liquide Canada Inc., Alberta Research Council [Org 4.2].

Funding level and funders Total cost unavailable: Sustainable Development Technology Canada, Natural Resources Canada, the Alberta Energy Research Institute, Alberta Research Council, and above corporate sponsors

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Proj 12.6: Enhanced coalbed methane recovery for zero greenhouse gas emissions (ARC)

Goal To advance the commercial viability of producing methane from Alberta coalbeds through the injection of CO_2.

Question addressed Can CO_2 be used to economically enhance the production of methane from coalbeds, and what is the fate of the CO_2 injected?

Project description The Alberta Research Council is leading a national and international consortium of more than 25 partners to demonstrate the technology of enhanced coalbed methane (ECBM) recovery. CO_2 or CO_2-rich flue gas (CO_2, NO_x, and trace gases) is injected into deep coalbeds and adsorbed in the coal matrix, displacing the CH_4 in the coal and creating a storage site for the CO_2.

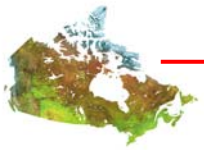
- Phase I was the initial assessment and feasibility of injecting pure CO_2 into deep Mannville coals.
- Phase II was the design and implementation of a micro-pilot test for injection of pure CO_2 in an existing CBM well located at Fenn–Big Valley in Alberta following Amoco Production Company procedures.
- Phase III was the assessment of reservoir response to varying compositions of injected flue gases and the design and implementation of a multi-well pilot project.
- Phase IV was the matching of novel combustion and separation technologies to produce a CO_2 waste stream with CBM reservoirs to carry out additional multi-well ECBM pilot tests.

To date, all testing undertaken in Phases I–IV has been successful, and the economics of the process have been assessed. This project is now into Phase V. The focus of this phase will be the design and installation of several multi-well ECBM pilots targeting various combinations of CO_2 sources and CBM formations.

Duration 1997–2010

Who is involved Alberta Research Council [Org 4.2]

Funding level and funders Approximately $4 million: International Energy Agency GHG R&D Programme, Environment Canada, Natural Resources Canada, Alberta Innovation and Science, Alberta Geological Survey, Saskatchewan Energy and Mines, U.S. Department of Energy, U.K. Department of Trade and Industry, Netherlands TNO, Japan Coal, Australian CSIRO, Gas Technology Institute, Suncor Energy, BP, Burlington Resources, Conoco Canada, EnCana Corporation, MGV Energy Inc., Exxon Mobil Canada, Husky Energy, PetroCanada, TransCanada Pipelines, EPCOR Utilities, TransAlta Utilities, Air Liquide, Sproule International, Tesseract, universities of Alberta and British Columbia, and BJ Services Canada



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Proj 12.7: Sustainable coalbed methane production: microbial regeneration of coalbed methane reservoir and CO_2 conversion to methane (ARC and others)

Goal To develop technology to enhance methane production in deep coalbeds.

Question addressed Can coalbed methane production through CO_2 injection be enhanced by microbial action?

Project description The production of CH_4 from coal in a sustainable fashion is being examined through a cyclic process that reduces CO_2 emissions to the atmosphere by injecting them into coalbeds, producing methane trapped in coal and regenerating more methane from CO_2 and coal by bacterial action. The end result is that the coal decreases slightly in volume, permeability increases, and the coal can later be mined for other purposes.

This project examines whether injected CO_2 could be biologically converted to CH_4, leading to an underground closed-circuit methane factory. Methanogenisis occurs naturally in many deep coalbeds. An induced methanogen culture would need access to the stored CO_2 (through slurry-fracturing techniques) as well as stoichiometric amounts of the reducing equivalent, H_2. The injection well would be shut in, and a suitable length of time would be allowed so that the methanogens could grow and produce CH_4 before the CH_4 is recovered by the production well. If necessary, nutrients can be introduced to the coalbed to stimulate microbial activity.

Duration 2002–2006

Who is involved The Alberta Research Council [Org 4.2], Terralog Technologies Inc., IISOKM Geochemical Consultants Ltd., and RMB Earth Science Consultants Ltd.

Funding level and funders $300,000: Government of Canada, province of Alberta, and private industry

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Proj 12.8: Degree of coal swelling and loss of permeability associated with sequestration of CO_2, H_2S, and flue gas: selecting optimum coals for sequestration (UBC/GSC)

Goal To investigate the relative swelling of a variety of Canadian coals in the presence of CO_2, flue gas, and CH_4.

Question addressed Which are the best coal deposits in which to apply CO_2 enhanced coalbed methane production?

Project description The research will test a representative suite of Canadian coals to establish their differential swelling under hydrostatic and differential stress conditions in the presence of CO_2 alone, H_2S and CO_2 together, and simulated mixtures of flue gases. To measure the change in permeability during gas injection, the work will use a specially constructed permeability apparatus that controls, monitors, and measures axial and radial stress and strain during injection. The results will be used to determine the affect of differential coal swelling on permeability and, hence, the ability to sequester gas in coal and other organic-rich rocks such as gas shales. The experimental results will be integrated in a numerical simulator to determine the feasible rates and volumes of CO_2 that could be sequestered with dynamic changes in permeability associated with coal-matrix volume changes. The results of this study will identify the most appropriate coal seams for enhanced coalbed methane recovery and CO_2 storage.

Duration 2003–2006

Who is involved University of British Columbia [Org 5.6]; Natural Resources Canada, Geological Survey of Canada [Org 3.3]

Funding level and funders $436,000 total: $361,000 from Natural Resources Canada (Climate Change Technology and Innovation)–; $75,000 from the University of British Columbia (NSERC)

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Proj 12.9: Experimental investigation of CO_2 and coal interaction (Calgary)

Goal To investigate the interaction between dense (high-pressure) CO_2 and coal, for the purpose of CO_2 storage and enhanced coalbed methane (ECBM) recovery.

Question addressed How different is the interaction of coal with dense, supercritical CO_2 than with gaseous CO_2, and how will this difference affect ECBM?

Project description This laboratory-based look into some fundamentals of coal and dense CO_2 interaction will use a combination of adsorption, X-ray imaging, and flow experiments. At conditions prevailing in some coal seams, CO_2 would exist as a liquid or as a dense, supercritical fluid. This situation may put rather stringent limits on CO_2 storage capacities in coal.

Dense CO_2 may interact with coal by mechanisms other than just physical adsorption. CO_2 may dissolve in coal, thereby changing its molecular structure and causing it to expand and become more plastic. What the storage mechanism of CO_2 in coal then becomes, and what effect dense CO_2 has on coal properties—permeability, storage capacity, and injectivity—is unknown.

Duration 2005–2007

Who is involved University of Calgary [Org 5.2]

Funding level and funders Total $112,000: Natural Resources Canafa (Climate Change Technology and Innovation via the CANMET Energy Technology Centre–Ottawa Clean Coal CO_2 Capture and Storage Strategy) and the University of Calgary (TIPM Laboratory)

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Proj 12.10: Time-lapse seismic monitoring of CO_2 injection into Ardley coals (CSEMP/Calgary)

Goal To investigate the effectiveness of seismic monitoring for guiding and monitoring CO_2 storage in coalbed methane (CBM).

Question addressed Can advanced seismic techniques provide effective monitoring of the behaviour of CO_2 injected into coalbeds?

Project description This project will conduct time-lapse surface and downhole three-dimensional and three-component (3D-3C) reflection seismic surveys and vertical seismic profiles at an enhanced coalbed methane (ECBM) production site operated by Carbon Storage and Enhanced Methane Production (CSEMP) and located in Alberta. Baseline surveys to image the Ardley coals are currently planned and will be executed within the first half of 2006. These surveys will provide an accurate depth model of the coals in the survey area, and will detect lateral facies changes in the coals that may inhibit gasification. Later datasets will be compared against the baseline measurements provided. The project will include seismic imaging of the CO_2 plume within the coal zone, seismic verification of CO_2 capture within the coals, development of monitoring protocols, and ongoing passive listening by geophones for detection and characterization of injection-induced reservoir fracturing.

Duration 2005–2008

Who is involved CSEMP, University of Calgary [Org 5.2]

Funding level and funders $915,000 total: Natural Resources Canada (Climate Change Technology and Innovation via the CANMET Energy Technology Centre–Ottawa Clean Coal CO_2 Capture and Storage Strategy), NSERC, Alberta Energy Research Institute, Weir-Jones, CSEMP Consortium, the University of Calgary (Consortium for Research in Elastic Wave Exploration Seismology and Institute of Sustainable Energy, Environment and Economy)

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Proj 12.11: Performance assessment and siting of CO_2 storage in coalbeds, combining probabilistic and deterministic methods (ECOMatters)

Goal To demonstrate the methodology of quantifying the capacity of overlying aquitards and saline aquifers to mitigate leakage of stored CO_2 from coal seams and to demonstrate how these methods could be used to assess siting criteria and wellbore sealing design.

Question addressed Can CO_2 be safely and permanently disposed of in deep geological formations (oil reservoirs, coalbeds, saline aquifers).

Project description This study will explore the concept that aquifers, in overlying coal seams in which CO_2 is stored, become an effective secondary storage site should CO_2 leak through wellbore seals or fractures in the coal-seam caprock. The project will employ CQUESTRA-2 (CQ-2), which can model leakage through wellbore seals up through a maximum of 50 geologic formations above the host coal deposit. Dissolution, diffusion, and convection processes will be evaluated in each formation to predict both vertical and horizontal migration of the CO_2 away from the wellbore into the aquifers. CQ-2 can be operated in either a deterministic or probabilistic risk analysis (PRA) mode. In the deterministic mode, high-resolution CO_2 concentration profiles can be generated to map potential CO_2 concentration gradients within any aquifer. The capacity of deep aquifers to function as natural secondary storage sites for the CO_2 will thus be systematically evaluated. Mapping of the potential spread of CO_2 within near-surface potable aquifers will also be carried out.

This study will seek to demonstrate that a combination of deterministic parameter studies and PRA provides a superior, comprehensive method of evaluating CO_2 storage options and of understanding the conceptual models of storage within a multi-layered geosphere. The methodology yields a statistical quantification of the uncertainty in the data used to populate conceptual models of the CO_2 storage process.

Duration 2005–2007

Who is involved ECOMatters Inc. [Org 8.17]

Funding level and funders Total $135,000: Natural Resources Canada (Climate Change Technology and Innovation via the CANMET Energy Technology Centre–Ottawa Clean Coal CO_2 Capture and Storage Strategy), ECOMatters, LeNeveu Simulations, Alberta Energy and Utilities Board

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13. STORAGE—RELIABILITY

Proj 13.1: Performance and verification assessment for geological storage of CO_2 (Alberta)

Goal To enable caprock parameters to be assessed for health, safety, and environmental performance of CO_2 geological disposal.

Question addressed How do the characteristics of caprock affect the performance of a CO_2 disposal site?

Project description This research project focuses on performance assessment of the caprock as a component of the overall health, safety, and environmental risk assessment of geological storage. Scale effects on the physical and fluid flow properties of the most common caprock material, shales, will be examined. The performance assessment will also include numerical parametric analyses to assess influence of physical and fluid flow property characteristics on integrity of shale caprock above CO_2 storage projects.

Duration 2002–2005

Who is involved University of Alberta [Org 5.8]

Funding level and funders Approximately $175,000 annually for each of three years: IEA GHG Weyburn-Midale CO_2 Storage and Monitoring Project (Petroleum Technology Research Centre) and NSERC

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Proj 13.2: Integrated, multidisciplinary assessment of coalbed methane reservoirs under primary and CO_2 enhanced recovery (Calgary)

Goal To understand the geomechanical processes associated with enhanced coalbed methane (ECBM) recovery through sequentially coupled reservoir–geomechanical simulations and laboratory experiments.

Question addressed How will geomechanical changes that accompany ECBM recovery affect CH_4 recovery and CO_2 storage?

Project description This research project incorporates the following tasks, some of which are carried over from Proj 12.2:

- Reservoir–Geomechanical Simulations (2003–2006): Effective modification to existing reservoir simulation codes to allow sequentially coupled reservoir–geomechanical simulations that appropriately account for the geomechanical behavior of the coals.
- Intact Coal Adsorption Behavior (2003–2007): Conduct CO_2 and mixed-gas adsorption tests on intact coal specimens rather than on crushed coal specimens so as to capture kinetics of adsorption under realistic *in situ* temperature, gas pressure, and effective stress conditions.
- Permeability–Stress–Adsorption Behavior (2005–2008): Experimentally establish the relationship between permeability and *in situ* stresses for Alberta coals and the influence CO_2 and mixed-gas adsorption and desorption have on the constitutive behavior of coals.
- Simulation Studies for Optimizing ECBM Recovery (2005–2008): Conduct extensive simulation studies to assess well placement and injection and production optimization strategies, including wellbore stability and suitability of horizontal and vertical wells for ECBM.
- Performance Assessment Study of ECBM Recovery Projects (2006–2009): Conduct performance assessment studies for two or three generic ECBM project scenarios within the province of Alberta to provide geomechanical input into analysis of risk associated with ECBM projects, such as damage to potable aquifers and wellbore leakage.

Duration 2005–2009

Who is involved University of Alberta [Org 5.8]

Funding level and funders $23,760 annually for each of five years: NSERC

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Proj 13.3: Multi-phase fracture flow modelling for underground CO_2 storage (Saskatchewan)

Goal To characterize the phenomena of gas and liquid flow in natural fracture replicas.

Question addressed What injection practices will maximize EOR and CO_2 storage in fractured reservoirs, and mitigate leakage through any fractures that might be present?

Project description This project involves the construction of a laboratory apparatus for monitoring multiphase flow in transparent replicas made from natural fractures in rock. When completed, it will give researchers the opportunity to use a high-speed digital camera to monitor the flow of gas bubbles through simulated fractures, while controlling brine and gas injection rates, brine salinity, fracture aperture, and fracture orientation. Analyses of these data, coupled with numerical modelling, will enhance our understanding of the factors controlling gas flow rates in fractured rocks.

Duration 2005–2006

Who is involved University of Saskatchewan [Org 5.1]

Funding level and funders $300,000 or more: Western Economic Diversification Canada and Weyburn-Midale Monitoring and Storage Project–Final Phase (applied for)

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Proj 13.4: Physical model studies of wellbore stability for underground CO_2 storage (Regina)

Goal To develop a model to predict the impact of various parameters on the stability of wellbores used for CO_2 storage.

Question addressed How much CO_2 will leak from storage sites because of pre-existing wellbores?

Project description This project will build a physical model of a wellbore in the laboratory. The resulting set-up will be used for simulating the reliability and integrity of wellbores for CO_2 injection, storage, and well abandonment practices. This project is conducted in the context that wellbores are the single most important potential source of leakage from underground storage of CO_2 in depleted oil and gas reservoirs or in combined CO_2 storage and EOR processes. The results will be used to develop a model for predicting wellbore integrity for CO_2 storage purposes and will provide guidelines for more effective methods of well abandonment at the end of CO_2 flooding.

Duration 2004–2008

Who is involved University of Regina [Org 5.3]

Funding level and funders $476,500 total: Natural Resources Canada, NSERC, Saskatchewan Petroleum Technology Research Centre and the Weyburn Monitoring Project, University of Regina

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Proj 13.5: Near and far field effects of CO_2 injection in geological formations: towards integrated monitoring and modelling protocols (ARC/Alberta)

Goal To develop an integrated approach to assessing and monitoring the behaviour of CO_2 storage sites.

Question addressed How can all the parameters that can affect the performance of CO_2 storage sites be integrated and used in modelling and monitoring?

Project description This project integrates experimental, numerical, and field-observation (monitoring) approaches in CO_2 injection with subsequent storage reliability and monitoring activities. Six major themes will be addressed:

1. Establish the constitutive behaviour of downhole cements used in western Canada, both pre- and post-exposure to CO_2, and develop rapid lab-based screening tests for cement suitability.
2. Establish the constitutive behaviour of various geological formations likely to be encountered in Western Canadian geological storage projects, especially formation response to injection-related phenomena and chemical interaction with CO_2.
3. Assess the usefulness of current, commercial reservoir simulation tools as a predictor and, in particular, the value of streamline simulation techniques.
4. Undertake extensive three-dimensional (3D) coupled simulations to explore the range of behaviours expected for wellbore systems of varying ages, geometry, and CO_2 injection schemes.
5. Develop and execute a strategy of development of downhole monitoring technology that integrates with standard oil and gas drilling and completion practices.
6. Formulate inversion methods for geochemically derived field performance measurements and their integration with the simulation technologies of theme 3.

Duration 2003–2008

Who is involved Alberta Research Council [Org 4.2] and the University of Alberta [Org 5.8]

Funding level and funders $1.6 million total: Natural Resources Canada, province of Alberta, province of British Columbia, province of Saskatchewan, Keyspan, Total, Penetrators, NSERC (University of Alberta), University of Calgary, University of California (Berkeley)

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Proj 13.6: Probabilistic risk assessment of the IEA GHG Weyburn CO_2 monitoring and storage project (ECOMatters)

Goal To demonstrate the methodology to quantify the capacity of overlying aquitards and aquifers to mitigate leakage of stored CO_2 from oil formations, and to demonstrate how these methods could be used to assess siting criteria and wellbore sealing design.

Question addressed Can CO_2 be safely and permanently disposed of in deep geological formations (oil reservoirs, coalbeds, saline aquifers)?

Project description Probabilistic and deterministic risk assessments were carried out by ECOMatters Inc. for the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project. Probabilistic risk assessment (PRA) is the preferred methodology for evaluating long, complex, process-driven problems such as the geological storage of CO_2. A unique, computationally-efficient model. CQUESTRA-1 (CQ-1). was developed to rapidly assess the thousands of cases that are required for a PRA and that statistically quantify the uncertainty associated with the many features, events, and processes, including their interactions over the long-term geological storage of CO_2. The project focused on the application of the PRA methodology to the Weyburn field and illustrated its use with data from an operating EOR pattern. Sensitivity analysis was used to identify the parameters that most influence releases to the biosphere and storage of CO_2 in the geological formations surrounding the reservoir.

Systematic deterministic calculations were used in determining trends attributable to single parameter variation or best- or worst-case scenarios using combinations of parameters identified from the PRA sensitivity analysis. The use of CQ-1 in a deterministic or risk assessment mode was illustrated with a base-case study that utilized the current best estimate of parameter values based on field or laboratory data and expert opinion.

Duration Phase 1: 2003–2004; Final Phase: 2005–?

Who is involved ECOMatters Inc. [Org 8.17]

Funding level and funders Phase 1: $200,000 IEA GHG Weyburn Project; Final Phase: Amount uncertain—IEA GHG Weyburn-Midale Project–Final Phase (applied for)

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Proj 13.7: Geological storage of CO_2: risk assessment and management (Calgary)

Goal To support risk management of geological storage of CO_2.

Question addressed How can CO_2 storage systems be designed for cost-effective risk management?

Project description This project will attack the risks of geological storage as a systems engineering problem by integrating risk assessment with reservoir engineering tools and monitoring methods. The focus will be on risk *management* rather than risk *assessment*.

The risks of geologic storage cannot be assessed in the abstract, because the risks strongly depend on storage system design. The project will develop an Integrated Geostorage Simulator (IGS) using a commercial multi-component reservoir simulator driven by geostatistical models. The reservoir simulator will, in turn, drive models that simulate the performance of advanced geophysical monitoring technologies. The integrated simulator will enable probabilistic predictions of CO_2 flow within reservoirs and simulation of monitoring reservoir conditions using geophysical methods.

The IGS will be applied to develop novel methods for engineering CO_2 storage in aquifers and for assessing risk. How methods of active reservoir engineering may increase storage capacity by increasing filling efficiency and may increase security by increasing the rate at which CO_2 is immobilized by dissolution or residual gas trapping will be explored.

Duration 2005–2008

Who is involved Universities of Calgary [Org 5.2] and Alberta [Org 5.8]

Funding level and funders $1.1 million: NSERC, Alberta Energy Research Institute, Alberta Energy, industrial partners

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14. STORAGE—MEASUREMENT, MONITORING, AND VERIFICATION

Proj 14.1: *In situ* monitoring methods for geological carbon sequestration (GSC)

Goal To develop seismic techniques to monitor underground movement of injected CO_2, and to assess levels of associated microseismicity.

Question addressed Can the movement and volume of injected CO_2 be monitored using surface measurements? Is there significant microseismic activity associated with CO_2 injection?

Project description This research will develop seismic imaging techniques for monitoring the dynamic response of geological reservoirs to CO_2 flooding, and will help assess the safety of underground CO_2 disposal. It will be carried out at Weyburn, Saskatchewan, in support of a multinational pilot project dealing with underground CO_2 sequestration. Verification of seismic monitoring techniques will be accomplished by comparison with statistics from production and injection wells.

Duration 2000–2009.

Who is involved Geological Survey of Canada, Natural Resources Canada [Org 3.3]

Funding level and funders Funding is provided through the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project.

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Proj 14.2: Automated soil-gas grid-sampling system (ECOMatters and others)

Goal To develop, test, and apply an automated gas sampling system in soils and sediments in a grid array around a borehole that is potentially leaking sequestered CO_2 to the atmosphere.

Question addressed Is sequestered CO_2 leaking around abandoned wellbores, and can it be detected by automated monitoring of CO_2 in soil gases?

Project description This project will assemble and test a gas sampling system that will detect and better quantify sequestered CO_2 for performance and risk assessment purposes. The proposed technology would use soil tubes emplaced in a grid-like array over or surrounding a structure potentially conductive for gases, such as a leaky well or a fault in underlying bedrock. The access tubes would be emplaced in soil 0.5–1 m deep and back-filled. These narrow-bore tubes would be connected to a central monitoring system set to sample and analyze soil gases using a pumping mechanism on any time scale of interest (for example, hourly, daily, weekly). The technology should be able to detect temporal changes and possible gas 'burps' attributable to ponding and sudden release of gas rising from a storage reservoir below.

Initial tests in an agricultural area near Pinawa, Manitoba, will look for background levels of CO_2 in a grassed area and will explore techniques of tube installation followed by activation of the centralized monitoring system. The system will then be set up to look for patterns and anomalies around or over either a wellbore that is potentially leaking gas or a known subsurface fault or major lineament in the Weyburn area. If this project is successful, future work may involve developing more systems for deployment elsewhere, such as in Alberta for the oil and gas industry.

Duration 2004–2008

Who is involved ECOMatters Inc. [Org 8.17] and Gascoyne Geo-Projects Inc.

Funding level and funders $244,000: Natural Resources Canada (Climate Change Technology and Innovation) and industry participants and suppliers

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Proj 14.3: IEA GHG Weyburn CO_2 monitoring and storage project—Phase I

Goal To monitor CO_2 sequestration mechanisms during a large-scale commercial EOR operation.

Question addressed Will CO_2 used for EOR remain in the reservoir?

Project description The International Energy Agency (IEA) Greenhouse Gas R&D Programme (GHG) Weyburn Monitoring and Storage Project–Phase I was an international research and demonstration project intended to establish the degree of security with which GHGs, particularly CO_2, could be sequestered in geological formations during large-scale commercial EOR operations. Those goals were accomplished through scientific mapping of the movement of CO_2 in the reservoir, and prediction of the future long-term storage and migration characteristics of the CO_2. The project was built upon a $1.5-billion world-class commercial EnCana CO_2 EOR operation at Weyburn, Saskatchewan, near the U.S. border with North Dakota. Beginning in 2000, CO_2 was captured at the Beulah, North Dakota, synthetic fuel plant (coal gasification) and carried by pipeline to the Weyburn EOR facility. Pre-injection baseline data and post-injection CO_2 monitoring have been underway for some years. The ultimate deliverables were a credible assessment of the permanent containment of injected CO_2 as determined by long-term simulations and formal risk analysis, and a generic business model for CO_2 storage through CO_2 EOR. It was determined that the geological setting at Weyburn was suitable for long-term storage of CO_2. Geoscience tools and a risk assessment model had been developed, demonstrating that CO_2 would not reach or penetrate potable water zones or the ground surface within the 5000 years of the assessment period.

Duration Phase I: September 2000–September 2004

Who is involved The commercial project is operated by EnCana [Org 8.1]; the monitoring project is coordinated by the Petroleum Technology Research Centre [Org 4.6] and involves 23 separate research providers from Canada, the United States, and Europe.

Funding level and funders $42 million: Natural Resources Canada, U.S. Department of Energy, Saskatchewan Industry and Resources, Alberta Energy Research Institute, European Community, IEA GHG R&D Programme, EnCana Corporation, SaskPower, Nexen Canada, Total, Chevron Texaco, BP Americas, Dakota Gasification Co., TransAlta Utilities Corp., ENAA (Japan), Petroleum Technology Research Centre

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Proj 14.4: Monitoring CO_2 fate at Penn West's Pembina Cardium CO_2 EOR pilot (ARC/AGS/Alberta/Calgary)

Goal To monitor the fate of the injected CO_2 in the Pembina Cardium oil reservoir to develop monitoring technology and learn about CO_2 behaviour.

Question addressed What is the fate of CO_2 when injected into the Pembina Cardium oil reservoir for EOR?

Project description This project is being put into place to provide support to the monitoring and validation aspects of the CO_2 injection pilot project at Pembina Cardium EOR site in central Alberta (see Proj 11.4). In late 2004, the Pembina Cardium formation was selected as the most suitable site for a comprehensive CO_2 monitoring initiative. This process involved the three other CO_2 EOR sites that were initiated under the Alberta government royalty credit program for CO_2 usage and the federal CO_2 Capture and Storage Incentive. A multi-disciplinary, multi-institutional team has been formed to advance monitoring techniques by using the opportunities in this EOR project to move the techniques from pilots to commercial operations. A framework for the monitoring program has been put into place; integrated technologies such as seismic imaging, geochemical analysis, and hydrogeology can document the motion of the injected CO_2 and detect potential leakage from the storage horizon. Injection of CO_2 started in early 2005, and geochemical sampling, analyses of formation fluids, and geophysical methods have been used to measure baseline conditions at the site. An observation well has been instrumented for data collection. Over the duration of the project, the results of these technologies will be integrated, and conclusions will be drawn as to the overall fate of the injected CO_2 and the most effective combinations of monitoring technologies.

Duration 2005–2010

Who is involved Alberta Research Council [Org 4.2], Alberta Geological Survey [Org 4.3], universities of Alberta [Org 5.8] and Calgary [Org 5.2]

Funding level and funders $3.75 million: Government of Canada (Western Economic Diversification, Natural Resources Canada, Environment Canada), Government of Alberta (Alberta Energy Research Institute, Alberta Environment), and Penn West

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Proj 14.5: Environmental Monitoring for Penn West CO_2-EOR Project (ARC)

Goal To provide assurance that injected CO_2 has neither leaked back to the surface, nor contaminated energy, mineral, or groundwater resources, and to provide an early warning should a leak occur.

Question addressed How can the reliability and performance of CO_2 storage be effectively monitored?

Project description This project complements Proj 14.5, but with an emphasis on environmental monitoring aimed at safeguarding health, safety, and the environment against risks of fluid or injected plume leaks from the reservoir into the shallow potable water zone or the atmosphere. The project will

- define local baseline hydrogeological conditions in the Paskapoo Formation, an extensive and highly-utilized shallow bedrock aquifer in Alberta.
- develop a comprehensive conceptual model of potential links between the surface and the subsurface, from a hydrogeological and hydrochemical perspective.
- identify potential receptors and pathways for exposure, to aid in defining and assessing risk.
- develop a monitoring approach that will provide sufficient key information to evaluate CO_2 geological storage.
- Serve as a liability safeguard.

The two primary technologies to be developed and applied for this project are atmospheric gas laser surveying, and groundwater monitoring and assessment.

Duration 2005–2008

Who is involved Alberta Research Council [Org 4.2]

Funding level and funders $417,000: CANMET Energy Technology Centre–Ottawa (Natural Resources Canada–Climate Change Technology and Innovation) and EnergyINet (amount shown does not include in-kind contributions from site operators)

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15. STORAGE—OTHER

Proj 15.1: Fixation of greenhouse gases in mine residues (UBC/GSC)

Goal To evaluate the feasibility of fixing CO_2 in mining wastes.

Question addressed Can large amounts of CO_2 be sequestered or stored through reaction with surface minerals?

Project description This academic project will examine the feasibility of storing atmospheric CO_2 in historical and active mine residues at mine sites in British Columbia, Yukon, and Northwest Territories Storage capacity is dictated by the size of the mine residues. Average-size mining operations could sequester from hundreds of thousands to millions of tonnes of CO_2. The study involves fieldwork and sampling, laboratory and experimental analysis, and geochemical modelling. It will examine the rates and processes of natural fixation of atmospheric CO_2 in a variety of mine residues. Depending on future funding and industry interest, this preliminary study may lead to demonstration or commercial research projects.

Duration 2003–2005

Who is involved University of British Columbia [Org 5.6] and Natural Resources Canada (Geological Survey of Canada) [Org 3.3]

Funding Level and funders Approximately $45,000: NSERC, B.C. Ministry of Energy, Mines and Petroleum Resources, Yukon Geological Survey

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Proj 15.2: Sequestering CO_2 by accelerated curing of concrete (McGill and others)

Goal To sequester CO_2 in concrete products through accelerated early-age curing in production.

Question addressed Can CO_2 be stored in concrete products as calcium carbonate?

Project description This research investigates CO_2 disposal by using concrete products as CO_2 sinks through an early-age accelerated curing process. The process involves the injection of CO_2, either recovered or as-captured, into the curing chamber at room temperature, the diffusion of CO_2 into fresh concrete under low pressure, and the conversion of gaseous CO_2 into solid calcium carbonates. The project examines the feasibility of using the gas captured from a cement plant for carbonation curing of three concrete products: masonry units, paving stones, and fibreboard. The project will also build a mathematical model to incorporate geochemistry and mass transport considerations. Preliminary studies have shown that CO_2 can be stably stored in concrete as $CaCO_3$ and permanently integrated into cement hydration products. Based on 20% uptake by the cement binder, the annual CO_2 sequestration would be 41,000 tonnes in one concrete paver production plant and 80,000 tonnes in one fibreboard production plant. As-captured flue gas can be used directly without separation; however its sequestration efficiency is lower than with purer CO_2. Without reinforcing steel, carbonated concrete products can have better strength and durability because of the depletion of calcium hydroxide. Such products can also be fabricated faster and with less energy consumption than occurs with conventional steam curing. Current research is aimed at enhancing the sequestration efficiency. A 25%–30% CO_2 uptake by weight of cement is targeted to achieve 50%–60% reaction efficiency. A demonstration project will be carried out.

Duration 2003–2006

Who is involved McGill University [Org 5.1], St. Lawrence Cement, and CJS Technology.

Funding level and funders $120,420 (2003–2004); $118,420 (2004–2005): NSERC

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Proj 15.3: High pressure studies on methane and CO_2 hydrates (McGill)

Goal To characterize the chemical and physical properties of CO_2 and CH_4 hydrates.

Question addressed What is the nature of hydrates formed by CO_2 at high pressure?

Project description This project will focus on the kinetics, morphology, and thermodynamic properties of gas hydrates, specifically CH_4- and CO_2-forming systems.

Duration 2004–2005

Who is involved McGill University [Org 5.1]

Funding level and funders 110,349 (2004–2005): NSERC

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Proj 15.4: CO_2 sequestration via gas hydrates (Calgary)

Goal To investigate the technical feasibility of storing CO_2 in hydrate form.

Question addressed Can CO_2 displace CH_4 and other natural gas components from gas hydrates while also sequestering CO_2?

Project description The research will evaluate the technical feasibility of storing CO_2 in hydrate form and displacing CH_4 from *in situ* CH_4 hydrates by CO_2 flooding. To proceed with the research, the formation and decomposition kinetics of hydrates in bulk water and in porous media need to be examined. The examination will include the kinetics of hydrate formation and decomposition from CO_2, CH_4, and mixtures of CO_2 and CH_4 in bulk water, followed by experimental studies of formation and decomposition of these hydrates in porous media. Thermodynamic predictions, Raman spectra, and kinetic parameters obtained from experimental data will then be used in the mathematical modelling of CO_2 sequestration in hydrate form.

Duration 2004–2007

Who is involved University of Calgary [Org 5.2]

Funding level and funders $273,000: Alberta Energy Research Institute

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Proj 15.5: CO_2 storage by mineral carbonation reactions: kinetic and mechanical insight from natural analogs (UBC/GSC)

Goal To assess mineral carbonation reaction pathways and mechanisms in geological analogs to CO_2 injection into serpentinite-hosted aquifers.

Question addressed Does fixation of CO_2 via carbonation of waste minerals offer a promising route to CO_2 sequestration?

Project description To assess the feasibility of permanently storing CO_2 in subsurface magnesium silicate rocks, this project examines geological analogs to mineral carbonation reactions. Project outcomes include establishing the mechanical and hydrologic consequences of mineral carbonation reactions, documenting reaction paths and mechanisms, and constraining the timing and rates of carbonation reaction in bedrock CO_2 alteration systems. The field site is Atlin in northwest British Columbia. Laboratory work occurs at the University of British Columbia.

Duration 2003–2005

Who is involved University of British Columbia [Org 5.6] and Natural Resources Canada (Geological Survey of Canada) [Org 3.3]

Funding level and funders Approximately $50,000: Natural Resources Canada

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Proj 15.6: Carbon sequestration in mine tailings (UBC/Western Ontario)

Goal To document carbon uptake in tailings of active mines and assess potential for acceleration of carbon uptake.

Question addressed Can mine tailings be used to mitigate GHG emissions?

Project description This project will document active fixation of carbon in mine tailings, identify the source or sources of fixed carbon, quantify the amount of fixed carbon, and identify the mineral hosts to fixed carbon. Experimental studies and geochemical modelling will assess the potential and methods for accelerating carbon fixation in tailings. A verification protocol for fixed carbon will be developed. Field sites are mines in Western Australia and Northwest Territories. Laboratory work occurs at the University of British Columbia and University of Western Ontario.

Duration 2005–2008

Who is involved Universities of British Columbia [Org 5.6] and Western Ontario [Org 5.1]

Funding level and funders $240,000: NSERC, WMC Resources Ltd., Diavik Diamond Mine Inc.

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Proj 15.7: Mineral carbonation in chrysotile mining waste: biological and chemical processes (Laval)

Goal To determine the mineralogic, chemical, and biological reaction pathways leading to spontaneous mineral carbonation and to permanent carbon sequestration in chrysotile mining and milling residues.

Question addressed Can asbestos tailings be used to fix and store CO_2?

Project description Asbestos mine and mill residues in Quebec's Eastern Townships represent 700 megatonnes of CO_2 storage capacity. To identify the amounts of hydromagnesite that naturally formed over time since the beginning of mining in the region, this project will investigate spontaneous mineral carbonation. Results will be compared with those obtained from hydromagnesite deposits in ephemeral lakes. The dissolution–precipitation pathways that lead to spontaneous natural hydromagnesite precipitation from magnesium-rich silicate minerals will be determined, as will the role, if any, of bacteria in catalyzing spontaneous mineral carbonation. The bacterial communities and the role of each type of bacteria in the process will also be determined. Applications could include atmospheric CO_2 scrubbing by spontaneous mineral carbonation in leach pads akin to hydrometallurgical processes used in the mineral industry to extract gold and copper, and innovative bioreactors to sequester carbon from an industrial stream.

Duration 2005–2008

Who is involved Département de géologie et de génie géologique, Université Laval [Org. 5.1]

Funding level and funders $130,000 over 3 years: Trans-Canada, Lab-Chrysotile, Mine Jeffrey, NSERC

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Proj 15.8: Sequestration of CO_2 in oil sands tailings streams (CETC-Devon)

Goal To develop a fundamental understanding of CO_2–oil sands tailings chemistry to permit the engineering of a co-storage process.

Question addressed Can CO_2 replace gypsum in oil sands tailings consolidation?

Project description The amount of CO_2 that could be sequestered in mature fine tailings from oil sands is only roughly estimated at this time at 0.3–3 megatonnes of CO_2 annually. This project examines the impact of CO_2 on process water chemistry, the long-term stability of the resulting consolidated tailings, and the long-term impact on water quality. The opportunity for improved bitumen recovery from tailings during the mature fine tailings transfer process will also be examined. CO_2 could reduce the amount of calcium required for the consolidation process and, at the same time, scavenge excess calcium as a calcite precipitate.

The consolidated tailings (CT) process (commercialized at Suncor) involves the transfer of mature fine tailings (MFT), addition of gypsum, and mixing with coarse tailings to create a material that can be eventually reclaimed as a soil. During transfer of MFT, bubbling CO_2 could be used to extract residual bitumen from the MFT. Absorption of CO_2 in the MFT would result in favourable properties relative to CT production. This manipulation of the MFT properties using CO_2 could result in a reduction of the gypsum requirement and ultimately reduce the ionic loading in the recycle water to the extraction process. Results suggest that chemical sequestration would at a minimum be 1200 tonnes of CO_2 per megatonne of conventional CT. The degree of CO_2 conversion to carbonate and bicarbonate is unknown, but could be as much as 10 times greater.

Duration October 2001–March 2005

Who is involved Natural Resources Canada (CANMET Energy Technology Centre–Devon) [Org 3.2]

Funding level and Funders $1.4 million: Natural Resources Canada, Suncor Energy Inc., and Canadian Natural Resources Ltd. (not including the cost of their large-scale demonstration)

Contact

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Proj 15.9: Methane production from CO_2-consolidated tailings (CETC-Devon/Alberta)

Goal Optimize the CO_2–consolidated tailings (CT) process to minimize or eliminate bacterial activity that leads to CH_4 production from tailings (and hence GHG emissions).

Question addressed Can the process of sequestering CO_2 in oil sands tailings also mitigate the release of CH_4 from these tailings?

Description This project is a follow-on from Proj 15.8.

Bacterial production of methane from tailings is a significant source of GHGs from oil sands production. The introduction of gypsum or CO_2 will change the bacterial activity and therefore potentially change the CH_4 production, perhaps eliminating it. The CH_4 production rates will be determined for three CT tailings treatments. The commercially implemented gypsum CT, CO_2–CT, and untreated CT. Production of CH_4 will be correlated to bacterial populations in the three mixtures. A significant shift in CH_4production would mean a significant GHG impact for these tailings treatment options. Identification of the corresponding bacterial culture could help to define further manipulations of the bacterial activity in CT mixes and to develop methods that further mitigate CH_4 production.

Duration April 2005–March 2007

Who is involved Natural Resources Canada (CANMET Energy Technology Centre–Devon) [Org 3.2] and the University of Alberta [Org 5.8]

Funding level and funders $300,000: Natural Resources Canada, Canadian Natural Resources, Suncor, University of Alberta

Contact

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Proj 15.10: CO_2 as a Vapex solvent (Calgary)

Goal To develop a bitumen recovery process that will result in sequestration of CO_2.

Question addressed Can we replace the CH_4 injected with C_3H_8 in the Vapex process with CO_2 to obtain a more environmentally friendly bitumen recovery method?

Project description The project is aimed at developing a CO_2-based Vapex process for *in situ* recovery of bitumen from tar sands reservoirs that will also provide substantial sequestration of CO_2. The program will involve investigation of the phase behaviour of the CO_2–C_3H_8-heavy oil system, and experimental evaluation of the CO_2-based Vapex process in semi-scaled physical model tests.

Duration 2003–2007

Who is involved University of Calgary [Org 5.2]

Funding level and funders $200,000: Alberta Energy Research Institute

Contact

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Proj 15.11: Application of algal photo-bioreactors for CO_2 sequestration: literature review and technology evaluation (CANMET-MMSL)

Goal To review the state of the biotechnology of algal photobioreactors with respect to CO_2 sequestration, and to recommend directions for future research.

Question addressed Can microalgae be used to absorb large quantities of CO_2 while producing fuels or other useful materials?

Project description The overall consensus of many experts in the field is that microalgae systems could actually be developed to achieve the very high productivities and low capital and operating costs for the production of renewable microalgae fuels, and could mitigate fossil fuel CO_2 emissions from power plants and other industrial sources.

In this work, the biotechnology of algal photobioreactors was reviewed with respect to identifying effective algal species, effective photobioreactor configurations, and important process parameters for CO_2 sequestration, based on the available literature and studies performed on coal-fired power plant flue gases and other applications. The report also provides an overview of algae cultivation technology as a means of CO_2 mitigation, considering the engineering and economic considerations. The report further looks at the capital and operating costs of large-scale algae production systems and identifies required areas of research.

Duration 2004–2005

Who is involved CANMET Mining and Mineral Sciences Laboratory, Natural Resources Canada [Org 3.5]

Funding level and funders $25,000: Natural Resources Canada, Climate Change Program

Contact

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PART C: ECONOMIC, SOCIAL, AND REGULATORY PROJECTS

16. EDUCATION AND OUTREACH

Proj 16.1: Towards a strategy for stakeholder engagement on geological carbon storage (Stratos)

Goal To provide guidance to the development of a stakeholder engagement strategy related to CO_2 storage.

Question addressed In determining whether CO_2 storage is adopted, how can key stakeholders be engaged in discussion of its acceptability?

Project description This study was commissioned to assist in the development of a strategy for stakeholder engagement with respect to issues involved in the geological storage of carbon. Through consultation with key players from federal and provincial governments, industry, research institutes, ENGOs, and risk-management experts involved in the development and oversight of carbon storage initiatives, the study examined these aspects:

- Need for and purpose of stakeholder engagement
- Potential stakeholder participants
- Activities and processes
- Delivery agents
- Measuring success
- Challenges for effective stakeholder engagement

The report discusses the implications of the wide range of views on the development of a successful stakeholder engagement strategy, and concludes with an identification of options for consideration ("next steps" needed) as a strategy for stakeholder engagement on carbon storage is developed.

Duration 2003

Who is involved Stratos Inc. [Org 8.20]

Funding level and funders $23,000: Environment Canada (CO_2 Capture and Storage Initiative)

Contact

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Proj 16.2: Building capacity for CO_2 capture and storage in the APEC region: a training manual for policy makers and practitioners (ARC and Delphi)

Goal To raise awareness and develop capacity to exploit the opportunities for CO_2 capture and storage in Asia–Pacific Economic Cooperation (APEC) countries.

Question addressed How can APEC countries realize the potential for CO_2 capture and storage?

Project description The Phase I study was commissioned by the APEC Energy Working Group and carried out by CO_2CRC in Australia. It identified potential sites and overall capacity. Phase II developed a training manual and delivered a two-day workshop in South Korea to build capacity and awareness regarding the potential for capture and geological storage of CO_2. Training materials include an overview for policymakers, extensive technical modules on all aspects of capture, transport, and storage, and modules covering economic, regulatory, health and safety, and public policy aspects. The training materials are targeted to developing economies and include guides for trainers and a community outreach strategy. In Phase III, the training manuals will be updated, workshops in China and Mexico will be delivered, and a preliminary assessment of geological potential in Mexico will be completed.

Duration Phase II (2004–2005); Phase III (2005–2006)

Who is involved Phase II: Alberta Research Council [Org 4.2] and the Delphi Group [Org 8.15]; Phase III: Alberta Research Council, the Delphi Group, and Carbon Technologies Pty Ltd. (Australia)

Funding level and funders Phase II: $154,000; Phase III: $117,000: APEC and the government of Australia

Contact

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Proj 16.3: Steps toward a strategic plan for citizen involvement for carbon capture and storage decisions in Canada (McDaniels/UBC)

Goal To help provide guidance and input toward a strategic plan for structuring and conducting citizen involvement regarding carbon storage policy decisions in Canada.

Question addressed How can the public be effectively engaged in discussions about implementation of CCS in Canada?

Project description The report is based in part on a one-day workshop where the following questions and issues were addressed:

- What level of activity should be expected regarding carbon storage to 2010?
- What are the objectives of citizen involvement (CI) for carbon storage?
- What role and responsibilities should be assigned to a future committee on CI?
- What kinds of risk communication formats and materials could such a committee design, coordinate, and employ?
- What messages and sources of information should be employed?

Duration 2003

Who is involved Tim McDaniels Research and the University of British Columbia [Org 5.6]

Funding level and funders $17,000: Alberta Environment and Environment Canada

Contact

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Proj 16.4: A Canadian primer on carbon capture and storage (The Pembina Institute)

Goal To write an overview of CCS for the public, outlining ways in which CO_2 can be captured and stored and the potential role of CCS as one tool in combatting climate change.

Question addressed What is CCS, what are the risks, and what role might CCS have in an overall strategy to reduce GHG emissions?

Project description The Primer reviews CO_2 capture technologies and transportation, examines the potential for geological and ocean storage, and looks at the issues of permanence and monitoring. The potential for geological storage in Canada is described and illustrated with maps. The chapter on policy initiatives includes sections on the International Panel on Climate Change, the Carbon Capture Project, the Carbon Sequestration Leadership Forum, and Canadian CCS initiatives. The final chapter examines the role of CCS in a GHG reduction strategy.

The anticipated date for publication on the Pembina Institute's web site is late November 2005. The Primer aims to provide information in a neutral manner. The Institute's position on CCS will be described in a separate document, which will probably be released at the same time as the Primer.

Duration May 2005–November 2005

Who is involved The draft report was written by Pembina Institute [Org 6.1] staff and has been reviewed by several members of the ENGO community and persons working within the oil and gas industry.

Funding level and funders This project was made possible through a contract with a private funder.

Contacts

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Proj 16.5: Public attitudes toward geological disposal of CO_2 in Canada (Simon Fraser)

Goal To assess current public views on the acceptability of CCS in Canada.

Question addressed What do ordinary Canadians know and think about CCS?

Project description This study is a two-phased approach that examines the acceptability of CCS technology to Canadians. In the first phase, focus groups were conducted in both Toronto and Edmonton to identify attitudinal differences between the two geographic regions (that is, CO_2 storage would take place in Edmonton but not in Toronto). The information obtained from the focus groups was then used to design an Internet-based survey for administration to a much larger sample of Canadians. The survey was administered to 1967 Canadians, with the Alberta and Saskatchewan sub-samples overweighted. The results of this work are now available.

Duration 2004–2005

Who is involved Simon Fraser University [Org 5.7] and M.K. Jaccard and Associates

Funding level and funders $30,000: Environment Canada and Alberta Environment

Contact

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17. ECONOMIC, SOCIAL & REGULATORY PROJECTS - OTHER

Proj 17.1: Advancement of a multi-tiered online auction web site designed to foster the development of a sustainable CO_2 market (The CO_2 Hub)

Goal To foster the development of a sustainable carbon dioxide (CO_2) market.

Question addressed How will suppliers and users of CO_2 and CO_2 credits transact business?

Project description The CO_2 Hub is a unique, multi-tiered online trading platform that facilitates transactions between buyers and sellers of CO_2 and emission reduction units. This auction web site was designed to foster and support the utilization of CO_2 for enhanced petroleum recovery, sequestration, and the trading of emissions credits.

In addition, stakeholders can seek auxiliary services (purification, compression, storage, and transportation) and benefit from an accurate tracking system to monitor volumes bought and sold in support of potential emissions credits. The Analyst's Hub facilitates stakeholder awareness of the opportunities and issues associated with the CO_2 supply chain. The CO_2 Hub is intended to foster price discovery and "best economics" for all related stakeholders.

Within *CANiSTORE,* The CO_2 Hub would serve well as the facilitation infrastructure, helping to link potential projects and partners, to monitor the CO_2 supplies delivered to the pilots, and to promote the development of the service infrastructure required for project commercialization.

Private and public investment is sought to further develop The CO_2 Hub to meet the particular needs of Canadian stakeholders (industry, government, research) as this market evolves.

Duration 3 years

Who is involved The CO_2 Hub Inc. [Org 8.9]

Funding level and funders Proposed cost $1 million; still being assembled

Contact

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Proj 17.2: Integrated economic model for CO_2 capture and storage (ARC and others)

Goal To develop a computer model to simulate the economics of connecting CO_2 emission point sources to EOR pools and ECBM coalbeds to induce incremental production of oil and gas and to store CO_2 in oil and gas reservoirs and in aquifers.

Question addressed What are the overall economic costs associated with CO_2 capture and geological storage initiatives?

Project description An evaluative numerical tool is being developed to assess storage options from both a business perspective (for example, project value, CO_2 credits) and a policy perspective (for example, emission reductions, taxes and royalties). This integrated model will be able to handle the four distinct businesses: CO_2 capture, CO_2 transport, injection and energy production, and CO_2 storage and credits. It will be able to evaluate individual project proposals and groups of projects (for province-wide impacts). The fiscal regime treatment and evaluation will depend on proper GHG accounting to generate credits, conventional injection and production economics, CO_2 capture economics, scenario analysis, and risk assessment. The integrated model will have an extensive list of capture options to choose from, a wide range of storage options, a range of business considerations, and a friendly user interface with tables and graphics outputs.

Duration 2005–2008

Who is involved Alberta Reseach Council [Org 4.2], Alberta Energy and Utilities Board [Org 4.3], Energy Navigator, SNC Lavalin, and the Computer Modelling Group [Org 8.11]

Funding level and funders $500,000: Natural Resources Canada, Energy Navigator Inc. (in-kind contribution—software development); SNC Lavalin Inc. (in-kind contribution—process engineering); Alberta Energy Research Institute (proposed)

Contact

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Proj 17.3: IEA GHG Weyburn–Midale CO_2 monitoring and storage project—Final phase

Goal To use the Weyburn–Midale experience to develop coherent public policies with respect to regulations, emission-credit trading, and a publicly acceptable approach to CO_2 storage.

Question addressed What regulatory, business, and communication issues must be addressed if CO_2 storage is to become accepted practice?

Project description This project is the second and final phase of this major CO_2-flood EOR demonstration. The first phase [Proj 14.3] addressed the field monitoring of CO_2 storage occurring in conjunction with an economic, $1 billion CO_2 EOR flood operated by EnCana Corporation of Calgary at Weyburn, Saskatchewan. This phase expands the geological domain to include the Midale field (operated by Apache Canada Limited) and will broaden its focus beyond technological challenges. This project will examine the regulatory, business, and communication issues that must also be addressed to enable large-scale application of CO_2 geological storage. This project will contribute to a clear, workable, science-based regulatory and GHG accounting framework for geological storage. The project will work toward the development of publicly-accepted, regulatory-approved, site-insensitive, and cost-effective industrial protocols for site selection, design, operation, risk assessment, monitoring, and quantitative and reliable verification of CO_2 storage volumes. Finally, the project will help to devise an effective public outreach and consultation process to ensure public understanding and acceptance of CO_2 geological storage as a key GHG mitigation strategy.

Duration November 2005–September 2009

Who is involved Lead co-sponsors are EnCana [Org 8.1] and Apache Canada [Org 8.2]. Other participants not finalized, but all members of Phase 1 have indicated interest, and additional organizations are expected to participate.

Funding level and funders Not yet finalized, but expected to be similar to Phase 1.

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Proj 17.4: Costs for capture and sequestration of CO_2 in western Canadian geological media (CERI)

Goal To provide comprehensive assessments of costs of CO_2 capture and storage in the Western Canadian Sedimentary Basin (WCSB).

Question addressed What are the likely costs of capturing CO_2 and storing it in geological formations in western Canada?

Project description This project provided detailed assessments of individual CO_2 sources and potential storage reservoirs. The mandate of this study was to develop benchmark costs for sequestering CO_2 in geologic media in the WCSB. These costs were based on available technologies for the use of fossil fuels and for capturing CO_2 from dilute emissions streams. Study methodologies and results were developed with the help of expert partners and were reviewed by knowledgeable steering committee members during the research program. The resulting estimates reflect near-term cost levels, with the expectation that research and development would lower those costs over time. These were the principal results:

- The most extensive and detailed inventory ever of CO_2 sources
- Development of comprehensive cost estimates for CO_2 capture from those sources
- Intensive evaluation of the full spectrum of oil and gas reservoirs in the WCSB for both cost and storage potential

Duration 2000–2002

Who is involved Canadian Energy Research Institute members and sponsors

Funding level and funders $250,000 from unnamed partners

Contact

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18. PROJECTS FOR WHICH INSUFFIENT INFORMATION WAS MADE AVAILABLE TO COMPLETE AN ADEQUATE SUMMARY

Proj 1.x: Glencoe Resources CO_2 capture, transport and storage project

Goal To take CO_2 from two petrochemical facilities and pipe it to an EOR project in Central Alberta.

Question addressed

Project description At the end of 2005, Glencoe began shipping CO_2 by pipeline from its new facility adjacent to the MEGlobal Canada Inc. plant at Prentiss, Alberta. A second facility, adjacent to the NOVA Chemicals Joffre, Alberta, petrochemical complex, is under construction and is scheduled to commence operations in early 2006, with its CO_2 output also entering the pipeline. When both facilities are operating, 220,000 tonnes of CO_2 will be piped and injected annually.

Duration 2005 - ?

Who is involved Glencoe Resources Ltd. [Org 8.22]

Funding level and funders

Contact

Glencoe Resources Ltd.
Calgary
(403) 233 8560

Proj 10.x: Simulation for CO_2 storage (Computer Modelling Group)

Goal To develop and improve simulation technologies for CO_2 storage in active or depleted oil and gas reservoirs, in coalbeds, and in aquifers.

Question addressed

Project description This research addresses improved modelling techniques for CO_2 EOR and storage processes in oil reservoirs, improved modelling of enhanced coalbed methane processes, and improved modelling of CO_2 storage in aquifers.

Duration

Who is involved

Funding level and funders

Contact

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Proj 14.x: Seismic monitoring for verification of the geological sequestration of greenhouse gases (Calgary)

Goal

Question addressed

Project description

Duration 2002–2005

Who is involved University of Calgary [Org 5.2]

Funding level and funders $91,000 (2002–2003); $97,000 (2003–2004); ??? (2004–2005): NSERC

Contact

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PART D: KEY STRATEGIC PLANNING DOCUMENTS

Doc 1.1: *Canada's CO_2 Capture and Storage Technology Roadmap* (2006)

What is it? *Canada's CO_2 Capture and Storage Technology Roadmap* describes the product of a structured process that identifies technologies, strategies, processes, and integration system pathways needed if CO_2 is to be captured and stored in Canada.

Role played in Canadian CCS The Roadmap is seen as a a common vision of requirements toward which all organizations conducting CCS-related activity can work.

Description The Roadmap exercise brings together Canada's experts from industry, academia, and government to

- define the current state of CCS technologies.
- provide a vision of future technology needs and requirements.
- map the various technology pathways and performance targets required to advance the technology to achieve the vision.

The intent is to have the tool developed and owned by the industry and supported by government and regulators. The Roadmap is expected to articulate a sound vision and to define clear performance targets and timelines. The Roadmap will address both a nearer-term market-transition timeframe, with consideration given to near-term growth and retrofit needs, and a 2015-and-beyond timeframe for technology pathways requiring longer-term development, infrastructure planning, and implementation.

Key elements include

- a survey of existing CCS technology roadmaps;
- a survey of industry issues and technology needs;
- preparation of a technology roadmap (TRM) strawman;
- development and maintenance of an interactive web site for communication purposes;
- workshops to bring stakeholders together to disseminate information, plan, and make decisions;
- studies by special advisory groups to identify technology pathways for key issues and needs;
- preparation and publication of the TRM.

Status The Roadmap has been produced in draft and is being prepared for publication in early 2006.

Where to find it Not yet available, but the TRM process maintains a web site at www.nrcan.gc.ca/es/etb/cetc/combustion/co2trm/htmldocs/mission_e.html.

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Doc 1.2: *Canada's Clean Coal Technology Roadmap* (2005)

What is it? *Canada's Clean Coal Technology Roadmap,* the product of a structured process, lays out a set of objectives and a strategy (championed by industry stakeholders) that will lead to the commercialization of clean coal technology (CCT) in Canada.

Role played in Canadian CCS The Roadmap focuses chiefly on technologies for the capture of CO_2 from coal-fired power plants (as well as plants operating on other carbon-rich fuels), a principal source of Canadian CO_2 emissions.

Description The Roadmap identifies technologies, strategies, processes, and pathways needed to allow coal to be used as a competitive, environmentally clean energy source for the production of electricity. It focuses on identifying technologies and energy-system pathways for power-plant retrofits and mid-term new construction, but it also looks at technologies for the 2020 timeframe, where longer-term development, infrastructure planning, and implementation are required. The Raodmap features

- a vision for the future use of coal in Canadian power generation.
- an outline of the critical challenges and expectations that confront coal's use.
- a detailed description of suitable performance standards for Canada's power industry.
- the identification of potential CCT pathways and highlights of other (global) CCT initiatives that may be of benefit to Canada.
- a review of the technology and innovation needed to develop these pathways in Canada.
- CCT objectives for Canada, and a strategy for meeting those objectives.
- a timeframe for developing the technology with recommended implementation targets.

Status The Roadmap was published in 2005.

Where to find it www.cleancoaltrm.gc.ca

Doc 1.3: *CANiSTORE* (2004)

What is it? The *CANiSTORE* document lays out planning options for technology and knowledge base development for the implementation of geological storage research, development, and demonstration in Canada. It is a companion document to *CANiCAP* [Doc 1.4].

Role played in Canadian CCS *CANiSTORE* has a double meaning. "Can I Store" is directed at the NGO community and is meant to address environmental issues and consequences. "The CANada Innovation geological STORagE" program is focused on technological solutions to storing GHG emissions in geological formations.

Description The main body of the report outlines a pathway for geological storage research in Canada connected to piloting, commercial demonstrations, and expanded commercial projects. The document's appendixes contain the financial projections and more detailed parts of the plan:

- A: The Role of the Geological Surveys
- B: Geochemical and Seismic Monitoring
- C: The Need for an Integrated Capture and Storage Economic Model
- D: A System to Facilitate Capture and Storage Transactions–The CO_2 Hub
- E: A Field Centre to Integrate Capture and Storage—The Industrial Heartland project
- F: Framework for International Activities
  - International Missions
  - International Secondments
  - International Collaboration
- G: List of Technologies and Knowledge Bases for Storage
- H: Financials

Status Published in 2004.

Where to find it www.co2network.gc.ca

Doc 1.4: *CANiCAP* (2005)

What is it? *CANiCAP* lays out planning options for technology and knowledge base development for the implementation of carbon capture and transportation research, development, and demonstration in Canada. It is a companion document to *CANiSTORE* [Doc 1.3].

Role played in Canadian CCS CANiCAP has a double meaning. "CAN I CAPture CO_2" is directed at the NGO community and is meant to address environmental issues and consequences. The "CANada innovation (CO_2) CAPture" program focuses on identification of technology systems that are or may be capable of delivery of CO_2 in a concentrated form that renders it readily useable, transportable, and storeable, and a business plan to put such technology systems into place.

Description The document represents a culmination of provincial, national, and international review documents and valuable feedback from an initial strawman on CO_2 capture and transport (based on discussions with more than 25 companies from across Canada). The main part of the report outlines a pathway for CO_2 capture and transport research in Canada based on research, piloting, commercial demonstrations, and expanded commercial projects, and the construction of a CO_2 backbone pipeline connecting large CO_2 emissions hubs. The backbone is driven by the need for H_2 for upgrading oil sands, and the need for reduction in CO_2 emissions across Canada by CCS.

Financial projections and more detailed parts of the plan are contained in the appendices:

- A: CO_2 Emission Hubs across Canada and the Proximity of Geological Sinks
- B: CO_2 Capture Technologies and Capture Opportunities
- C: Economics of CO_2 Capture from Power Plants Considering Near Term to Longer Term Breakthrough Technologies
- D: A Selection of International Activities Related to Carbon Capture
- E: Opportunities at Oil Sand and Heavy Oil CO_2 Emission Hubs
- F: Opportunities at Electricity CO_2 Emission Hubs
- G: Opportunities at Petrochemical CO_2 Emission Hubs
- H: Opportunities at Multi-Industrial CO_2 Emission Hubs
- I: Off-Gas from Oil Refineries and Bitumen Upgrading
- J: Opportunities for a CO_2 Backbone Pipeline

Status Published in 2005

Where to find it www.co2network.gc.ca

Doc 1.5: IPCC *Special Report on Carbon Dioxide Capture and Storage* (2005)

What is it? The *Special Report on Carbon Dioxide Capture and Storage* was prepared under the auspices of Working Group III (Mitigation of Climate Change) of the Intergovernmental Panel on Climate Change (IPCC) to assess the scientific, technical, environmental, economic, and social aspects of capture and storage of CO_2. The report was developed in response to an invitation of the United Nations Framework Convention on Climate Change (UNFCCC) at its seventh Conference of Parties (COP7) in 2001.

Role played in Canadian CCS A number of Canadians participated in the preparation of the IPCC Special Report as authors and reviewers. The report is a thorough review of current knowledge and potential and is especially important in moving toward acceptance of CCS by the international community and the UNFCCC as a recognized GHG mitigation option eligible for tradable credits.

Description The scope of the report includes the assessment of technological maturity, technical and economic potential to contribute to mitigation of climate change, and costs of CCS. It also includes legal and regulatory issues, public perception, environmental impacts and safety plus issues related to inventories and accounting of GHG emissions reductions. It identifies gaps in knowledge that would need to be addressed to facilitate large-scale deployment.

The structure of the report follows the components of a CCS system. An introductory chapter outlines the general framework for the assessment and provides a brief overview of CCS systems. Chapter 2 characterizes the major sources of CO_2 that are technically and economically suitable for capture so that the feasibility of CCS can be assessed on a global scale. Technological options for CO_2 capture are discussed extensively in Chapter 3, while Chapter 4 focuses on methods of CO_2 transport. In the next three chapters, each of the major storage options is addressed: geological storage (Chapter 5), ocean storage (Chapter 6), and mineral carbonation and industrial uses (Chapter 7). The overall costs and economic potential of CCS are discussed in Chapter 8, and an examination of the implications of CCS for GHG inventories and emissions accounting is given in Chapter 9.

Status Published in 2005

Where to find it www.ipcc.ch