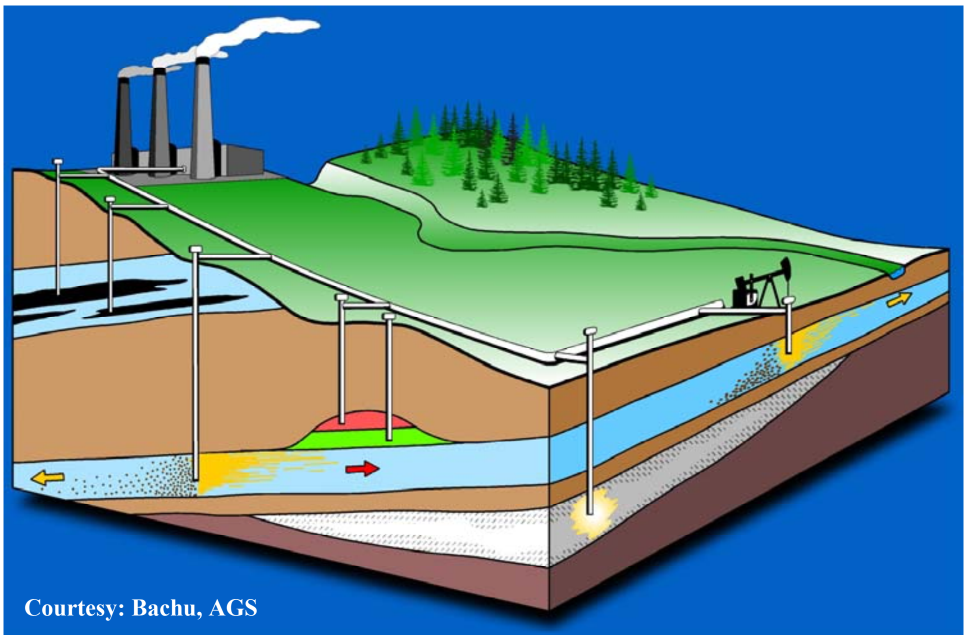
The CANiSTORE Program

Planning Options for Technology and Knowledge Base Development for the Implementation of Geological Storage Research, Development and Deployment in Canada



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Executive Summary

CANiSTORE has a double entendre. “Can I Store” is directed at the non-governmental organizational (NGO) community and is meant to address environmental issues and consequences. “The CANada Innovation geological STORagE” program is focused on technological solutions to GHG emissions. Both goals are embodied in CANiSTORE.

The impetus for this document grew from a May 23, 2003 workshop hosted in Calgary by the Alberta Energy Research Institute (AERI), Alberta Environment (AENv) and Natural Resources Canada (NRCan) where the mandate was given to establish a governance framework and a technology framework for developing a “Canadian Network of Innovation in Carbon Geological Storage” (CANiSTORE). At that time, Bob Mitchell, then a Director with Alberta Environment, was chosen to lead the governance framework development and Bill Gunter, Distinguished Scientist, Alberta Research Council was chosen to lead the development of the technology framework. This document focuses on the later, the development of a technology framework.

A draft high level plan and a strategic vision document were distributed for review in the fall of 2003 with the intention of incorporating critical review comments into the development of a detailed technical plan that would also be consistent with the governance framework.

Changing landscapes of people, programs and participation subsequently lead to a refocus of the mandate to primarily guide the development of a technology strategy for geological storage in Canada. The document reported herein represents a culmination of all the initial documentation, review comments received from AERI, AENv and NRCan and the valuable feedback from other organization and industry representatives through the CO_2 Technology Roadmapping Workshops.

The main body of the report outlines a pathway for geological storage research in Canada connected to piloting, commercial demonstrations and expanded commercial projects. Financial projections and more detailed parts of the plan are contained in the appendices (i.e. 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, a. International Missions, b. International Secondments, c. International Collaboration; G: List of Technologies and Knowledge Bases for Storage; H: Financials)

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BACKGROUND

Until a few years ago, there were basically only two ways to address the challenge of greenhouse gas (GHG) management. One was to produce and use energy more efficiently. The second was to rely increasingly on low-carbon and carbon-free fuels. As a result, Canada has made great strides in energy efficiency and substantial progress in bringing down the costs of alternative and renewable energy. But when the most credible projections for escalating energy use around the globe in the next century are extended to the predicted rising levels of carbon emissions likely to result, it is readily apparent that energy efficiency and alternative energy, alone, may not be enough to stabilize global concentrations of carbon dioxide. Such an effort would assume that all nations of the world, developed and developing, undertake a massive overhaul of their energy infrastructures in a relatively near, and relatively quick, time frame.

Carbon sequestration offers the world and Canada a third option. An option that now and more so in the future will be proven affordable, effective and environmentally safe, and most importantly an option that, if validated, will mean that the Canada will be able to take advantage of an abundant and low cost energy resource. Carbon sequestration activities will be required where CO_2 is sequestered in the biosphere, in oceans and in deep geological formations. Of these three areas, Canada's geological media seems to offer an environmentally benign haven for storage of CO_2 for long periods of time.

The serendipitous relationship exists that in the sedimentary basins during fossil fuel production from geological media, pore space that was occupied by oil and gas for geological time can be refilled with anthropogenic CO_2, a key to reducing atmospheric GHG emissions. Or in other words, the cause of the problem (burning of oil and gas produced from fossiliferous sedimentary basins) is the solution to the problem.

The geological storage of CO_2 in Canada is deemed by many scientific researchers and engineers to offer a cost effective transitional solution that allows the world to continue using fossil fuels and curb CO_2 emissions at the same time. By the time capacity increase in the other options is sufficient to displace fossil fuels, the supply of fossil fuels will have decreased substantially and a smooth transition is envisaged.

To accelerate the commercialization of geological storage of carbon dioxide (CO_2) by developing and applying technology in field pilot projects tests, the formation of a strategic network of innovation is proposed. The justification for the network presupposes that a CO_2 emission constrained world will exist with ceilings on CO_2 emissions to the atmosphere under a cap and trade scenario. If this happens, geological storage will grow from the present small number of industry operations to become a wide ranging, fully integrated new industry – an industry in which Canada must adequately and transparently prepare for thorough objective and science based testing and knowledge growth of a variety of GHG geological storage technologies.

The geological sequestration process consists of "capture", including purification, of site specific anthropogenic CO_2 emissions, "transport" of a concentrated CO_2 waste stream and "storage" of the CO_2 by injection into deep geological media consisting of active and depleted oil, gas and coalbed methane (CBM) reservoirs, saline aquifers and salt caverns.

Canada is one of the initial world leaders in geological sequestration of carbon dioxide, along with the Netherlands and Norway. Recently, the US government has begun investing large amounts of money in geological sequestration programs ($50 million annually), and has bought together thirteen nations, including Canada, to form an alliance for developing and implementing this technology through a Carbon Sequestration Leadership Forum (CSLF). As well, industry in the U.S. awarded Stanford University $225 million over a 10-year period for a Carbon Management program. Australia is also actively investing in CO_2 capture and geological storage by means of a newly established CO_2 Cooperative Research Centre (CRC) that will operate with a budget of exceeding $120 million over 7 years. Canada's investment in geological sequestration needs to be increased in order to keep Canada as a leader in this area, to build on existing projects and to maintain the momentum for developing commercial applications specific to Canadian circumstances.

On the capture side of geological sequestration, Canada is well positioned. A Capture Centre has been established in Saskatchewan at the International Test Centre at the University of Regina. In parallel, NRCan at Bell's Corner in Ottawa is operating enriched-oxygen combustion and gasification labs. Industry has responded with the Canadian Clean Power Coalition (CCPC), a public-private partnership that aims to demonstrate CO_2 removal from an existing coal-fired power plant by 2007 and from a new power plant by 2010. As well, work is underway by the Zero Emission Carbon Alliance (ZECA), a consortium formed to design a zero emissions coal-based power plant.

On the storage side of geological sequestration, Canada has initiated field projects on monitoring of the Saskatchewan Weyburn Enhanced Oil Recovery (EOR) flood, the Alberta CO_2 storage and Enhanced Coalbed Methane Recovery (ECBM) pilots and a review of the 42 Acid Gas (H_2S and CO_2) injection sites in western Canada. In addition, Alberta Energy and NRCan have established incentive programs for CO_2 enhanced recovery that is expected to shortly lead to field projects involving the injection of CO_2 and the production of oil and gas.

Canada also has several projects assessing the capacity of Canadian Sedimentary Basins for CO_2 storage led by the Geological Surveys. The first phase (succeeding phases would require more funding) of the Weyburn monitoring project is nearing completion. The ECBM project has successfully completed a number of single well tests and requires additional funding for a multi-well pilot. The acid gas project will evaluate sites for monitoring this year and will require additional funds for a monitoring program next year. As well, the monitoring of the CO_2 enhanced recovery projects, which are expected to start operations in Alberta this year, will require significant new resources for active monitoring.

While these projects provide a powerful platform for the federal and provincial governments to develop effective strategies in geological sequestration, the range of geological reservoirs, emission streams, geographic location, etc. lends itself to a diverse view of the path forward for geologic storage. To improve Canada's focus on geological storage, the scope of work and budget for the development of a business plan provided in this proposal, describes an integrated program centred on sedimentary basin capacity evaluation and on field projects which developing technology feeds into - leading to commercialization of CO_2 storage.

RATIONALE FOR CANISTORE

There are major questions of how the development of technology for carbon capture and storage through innovation would impact the future potential GHG reductions, and how much investment should be made in research, development and deployment (RD&D). While much is known about past technological change, much less is known about future technological change[1]. The uncertainties include: where inventions will come from; what inventions will become successful; what any given dollar of R&D will return; how much learning will occur; how quickly a particular product or process will diffuse into wider use; or where the next big breakthrough will come. There is no evidence in the literature that any single technology will provide society with the ability to control the cost of emissions mitigation. However, evidence does suggest that a suite of new and improved technologies will become available over time.

The current understanding of technological progress and its relationship to environmental goals comes from integrated economic, energy, and environmental system models. Numerous international and regional studies using the various modelling approaches (top-down, bottom-up) have been conducted to understand and examine how climate change objectives should be achieved. The current state of the art is the acknowledgement that modelling the rate of technological change is in its infancy. While relatively simple models can be built to illustrate the effects of inducing technological change through RD&D expenditures, through learning-by-doing, and through price, these models fall far short of the complexity of the real world. In the future, there are two promising approaches to developing a better understanding of the role of technology in addressing the climate change issue. The first is to combine the best features of the top-down and bottom-up models in a single modelling framework – introducing better engineering representations into a consistent, general, energy-economic setting. The second is to continue to pursue the development of fully synthesized models of technological change. Both approaches help estimate the costs of policy as well as identify and rank technology opportunities.

The goals of CANiSTORE's science, technology, policy and performance development and execution of pilots or demonstration projects would provide the following valuable return on investment for the stakeholders:

- Direct tonnes of CO_2 sequestered in the pilot and demo projects;
- Lower operating costs through operational improvements and reductions in energy consumption, resulting in strengthened industry viability;
- Lowering costs and reductions/elimination of GHG emissions to improve the industry's competitiveness and solidify Canada's place in the international market;

[1] Technology Change and Its Effects on Mitigation Costs, J. Edmonds et al., Climate Change: Science, Strategies and Solutions, Pew Center on Global Climate Change, 2001.

- Number and strength of collaborative partnerships to optimize research investments and provide scientific knowledge, new technologies and better practices for the industry as a whole;

- Number of highly qualified personnel (HQP) that are trained in Universities/colleges as a result of network operations; and

- Size of leveraged industry funds.

Other co-benefits include:

- Addressing energy supply, demand and application, while bearing in mind the potential for symbiotic interaction between energy sources.

- Resolving the environmental, supply, and reliability constraints of producing and using energy resources to provide Canadians with a stronger economy, healthier environment and more secure future.

- Creating linkages and opportunities for wastes from one industry sector as resources in another.

- Developing technologies and processes to address existing pollutants (NOx, SOx, particulates, mercury). These pollutants could be significantly reduced, if not eliminated.

INTRODUCTION

This document provides an overview of the options and elements needed to guide Canada's long-term research effort into climate change mitigation potential of geological storage. It is hoped that the document will guide the coordinated efforts of the stakeholders participating in the Canadian CO_2 Capture and Sequestration Technology Network (CCCSTN). This document responds to:

- The Alberta Energy Research Institute Energy Innovation Network (EnergyINet) program in CO_2 management - to reduce greenhouse gas and other emissions by developing technology to capture, transport, and use carbon dioxide to increase oil and gas recovery and inject into coal beds to release methane; and

- The Canadian CO_2 Capture and Storage Technology Network (CCCSTN) – established due to interest and initiatives underway for the implementation of CO_2 capture and storage technologies. CCCSTN has been established to coordinate activities undertaken by various groups and/or entities working on research, development and demonstration of national CO_2 Capture and Storage (CO_2 C&S) initiatives.

The relationship between these two organizations and the capture and storage initiatives underway in Canada is illustrated in Figure 1. It is intended that this document provide input and pathways to aid in the development of a detailed business plan that includes both governance, funding and technology issues, to be developed by a program director, a position administered by the Alberta Energy Research Institute and the EnergyINet program.

Vision

Canada, through the CANiSTORE network, is a world leader in knowledge and technology application for all aspects of greenhouse gas geological storage.

Mission

To enhance the knowledge, awareness, competency, and global competitiveness of Canada through the:

- Development, adoption, adaptation and demonstration of cost effective transitional technologies in Geological Storage.

- Implementation of technologies in Canada to significantly decrease CO_2 emissions to the atmosphere from major stationary CO_2 sources.

- Derivation of benefits from Canada's abundant natural resources and existing industrial base.

The mission will be achieved through technology development and field pilots, and the continued implementation of Canadian commercial projects for CO_2 storage in geological media.

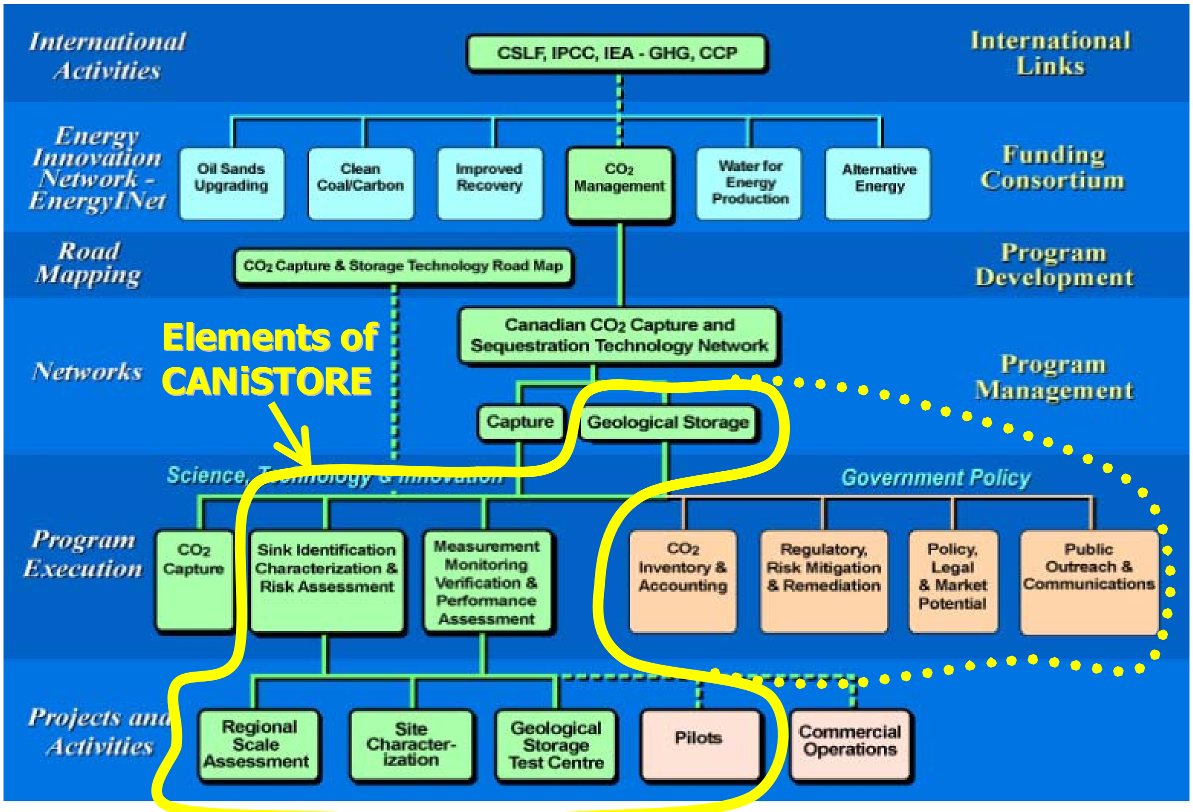

Figure 1: Relationship of CANiSTORE with respect to programs/activities in Canada (Courtesy: Bachu, AGS).

Values

The following core values and beliefs will contribute to CANiSTORE's success:

- Commitment and Accountability to stakeholders
- Leadership and Teamwork – in engaging and accelerating collaborative action, provincially, nationally and international that supports the longer term vision
- Passion for Innovation – believing that we can develop and effectively deploy technology into the economy
- Respect and Integrity - be honest and trustworthy in all our relationships

Strategic Goals

CANiSTORE will contribute to the following desired end-states:

- Focus the skills of the appropriate Canadian Research Organizations on solving technology barriers to implementation of geological storage of greenhouse gases in Canadian sedimentary basins

- Increase the awareness and perception of the Canadian public in geological storage as a safe solution for reducing greenhouse gas emissions
- In partnership with government and industry, establish geological storage piloting activities in Canadian sedimentary basins
- Accelerate the commercialization of geological storage though successful piloting leading to demonstrations

By developing knowledge with the aim of achieving these goals, CANiSTORE will ensure that it addresses the most important geological storage issues. For each of the goals, CANiSTORE will prepare technology-based solutions that support government policy discussions and decision-making and industry business initiatives.

Measures of Success

The development of realistic, quantifiable measures, to give substance to the strategic goals and to demonstrate progress in achieving them, will be a key deliverable of the business plan to be developed by the proposed CANiSTORE Program Leader in concert with the overall governance direction provided by the Carbon Capture and Geological Storage Network. In the short term, the following measures are representative of reasonable aspirations and targets for CANiSTORE:

- Accelerating the commercialization of geological storage and be indirectly responsible for the storage of 25 megatonnes of CO_2 in geological media by 2012
- CANiSTORE will develop an appropriate business model and seek to become self-supporting within 10 years of initiation.

Strategic Objectives

These key outputs support our vision, strategic goals and measures of success:

- Meeting CO_2 emission targets yet maintaining low cost power derived from fossil fuels
- Avoiding the future need to purchase carbon credits internationally but being able to sell Canadian geological storage credits internationally
- Providing a sustainable future for major energy exports worth tens of billions of dollars
- Developing new commercial opportunities via new technologies, and in the longer term through integrated regional emission-free hubs, a precursor of a hydrogen economy.
- Decreasing CO_2 emissions in an environmentally sustainable manner
- Providing part of the solution to a major environmental problem, yet maintaining the social benefits of economic growth

TECHNICAL PATHWAYS

The major business function of the Canadian Network of Innovation in Carbon Geological Storage will be the design of, development of, execution of and participation in geological storage pilot projects, demonstrations and as tag-on's to commercial projects as they come on line. To support the pilot projects and to ensure that the maximum amount of information beneficial to the early establishment of a geological storage industry in Canada is obtained from these pilot projects, the operation of CANiSTORE will be separated into three core support units:

- Program Management;
- Pilot and Demonstration Projects; and
- Research and Development Programs.

Figure 1 provides a general structure for the operation of the network. It is anticipated that achieving the goals set for CANiSTORE will require a pilot project to be initiated and executed followed by a demonstration project within the network. Equally important will be the collaboration of CANiSTORE with external projects. As shown in Figure 2, the program would be lead by a Program Leader with assistance for finance and accounting functions. The Pilot and Demonstration Programs and the Research & Development Programs would be lead by managers seconded to CANiSTORE from AERI, AENv or NRCan, individuals from associated Research Organizations and/or industry. The scientific advisory committee advises both the governance board and the program management team on technology decisions. The managers of pilot & demonstration projects and the research & development programs must work closely together.

Policy research and performance programs are split into regulation and outreach, life cycle evaluation and economics, and risk and performance assessment. Science and technology development is split into pipelining and surface facilities, measurement, monitoring and verification, co-optimization and storage engineering, containment engineering, mitigation technology, well technology, well characterization, reservoir characterization and regional characterization. Basin evaluation that assesses basins for the most suitable areas for geological storage is a task of the geological surveys and leads directly to regional evaluation of the most favourable areas.

CANiSTORE should aim to collaborate in all geological storage projects in Canada. Although it will initiate some projects with industry as the operator, it will also invest in existing projects (i.e. called external project liaisons in Figure 2). The information flow from these projects will be aligned with and applied to the Centre's own field pilots to make maximum use of the external data. This will also aid in ensuring the development of an integrated, holistic framework for a geological storage industry in Canada.

Commercial projects leading to geological storage are currently hampered by the physical separation between industrial CO_2 waste streams and suitable reservoirs for injection of CO_2 (i.e. lack of pipelines for CO_2 transport). The Alberta Government has identified this issue as a priority and they are currently proposing new fiscal policies that would encourage the building of CO_2 pipelines and CO_2 storage demonstrations. These provide opportunities for technologic development. However, investment should be based on opportunities that access as wide a variety of storage reservoir types as possible. While the Weyburn reservoir represents one type of carbonate reservoir, it for example, is not typical of Alberta carbonate reservoirs. Consequently, it is desirable to have CO_2 geological storage projects (which are individual Nodes of the CANISTORE) in other geological settings in other provinces/sedimentary basins. In fact, there are favourable geological settings that can access several types of reservoirs vertically and sitting directly below large CO_2 sources and linked to oil and gas infrastructure. Based on a review of current suitable sites within the Province of Alberta, the most suitable candidate site is the Ft. Saskatchewan area (see Appendix E). It is a large industrial complex which has several types of CO_2 waste streams, it overlies a range of geological storage reservoir types including CBM and saline aquifers, the portion of the sedimentary basin where this industrial complex is located is in a mature stage for CO_2 injection (i.e. depleted in oil and gas), easily accessible to oil and gas industry infrastructure, and to the oil and gas producers.

Business Objectives/Guiding Principles

- Establish network of scientists and engineers for geological storage in the technology areas: Top-Down Sedimentary Basin Evaluation, Regional Geological Site Characterization, Reservoir Characterization, Well Characterization, Storage Engineering, Containment Engineering, Mitigation Technology, Added Value Technology (e.g. EOR), Pipelining, Well Technologies, Performance Assessment, Life Cycle Analysis and Economic Modelling within one year
- Provide advice for Regulatory/Legal framework for Geological Storage by engaging the appropriate bodies (e.g. Alberta Energy Utility Board) with a plan in place within two years
- Conduct a comprehensive outreach program that is developed by government departments within the first year
- Nationally and internationally accepted audit and verification procedures for geological storage
- Identification of ten geological sites within five years suitable for storage of CO_2 for thousands of years or longer – with evidence demonstrating to communities and governments that geological storage is environmentally sustainable
- All technology projects funded by the CANiSTORE are tied into field pilots
- Completed or in operation, five geological storage field pilots which are recognized as nodes of the Centre within five years.
- Three commercial operations developed and running as a result of technology developed through the field pilots within seven years.

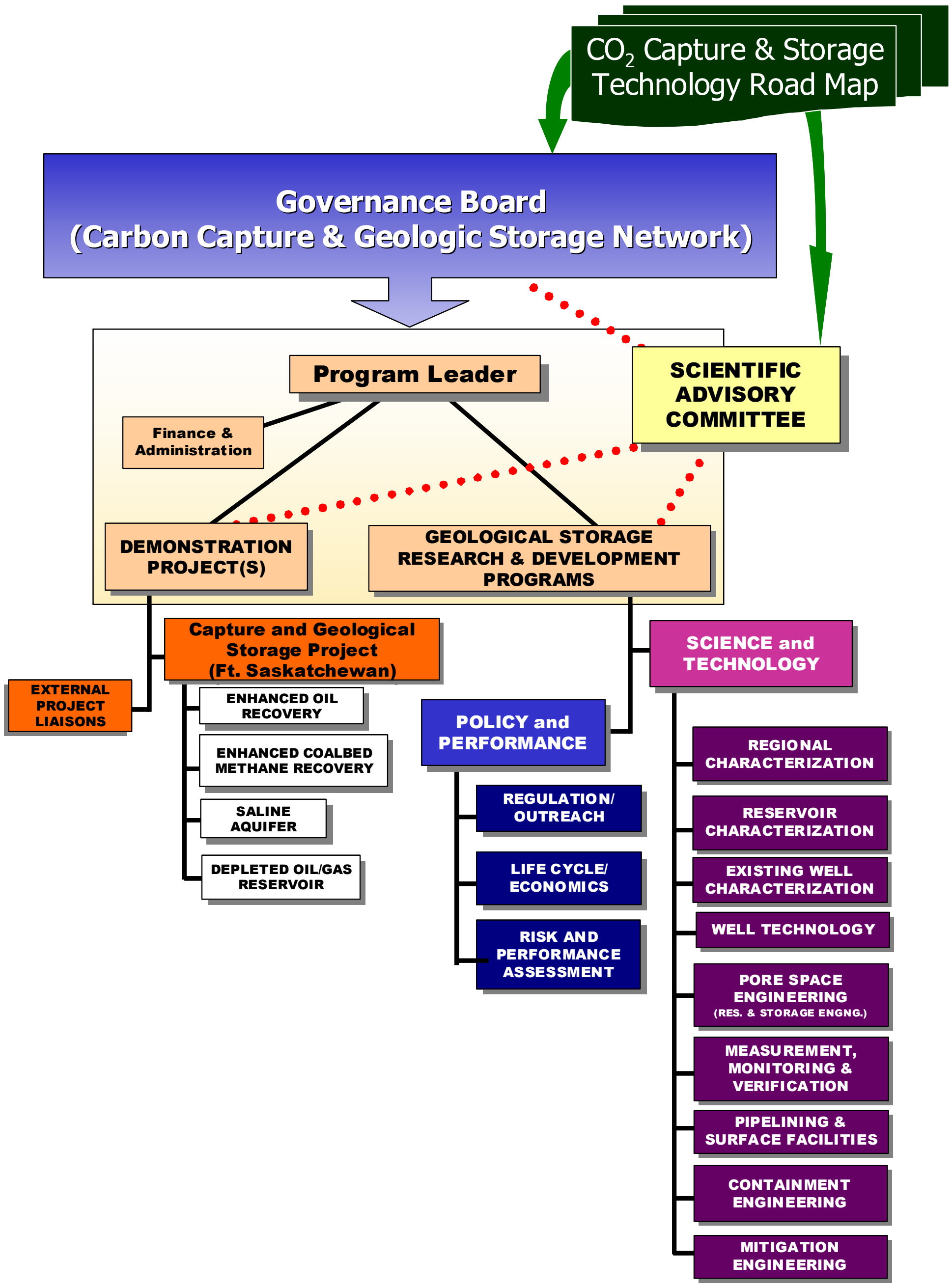

Figure 2: General organization of geological storage program undertaken by CANiSTORE

Business Context and Critical Factors

- CANiSTORE is being set up to accelerate a potential new global industry – that of reducing CO_2 emissions to the atmosphere by storage of CO_2 in geological media.
- Canada has the knowledge resource to develop and implement geological storage, and has been at the forefront of this technology development for several years.

- The establishment of the CANiSTORE presupposes that the global community will attach a dollar value to reducing CO_2 emissions that will exceed $10 to $50Cdn/tonne CO_2 avoided. If the CO_2 were from coal-fired electrical power plants, the cost of coal-fired electricity would be increased by approximately 20 to 40%, which is equivalent to $57/tonne CO_2 for each tonne of CO_2 stored. Although this might seem to be a prohibitive cost, it will lead indirectly to implementation of Clean Coal technologies that will have other environmental benefits. This is the biggest uncertainty that the business faces.

- Another important issue is the containment of the CO_2 in geological media. Leakage form the storage reservoir must be minimized and leakage that does occur must be identified and steps taken to avoid any unsafe situations.

Strategic Themes

The focus of CANiSTORE is testing geological storage technology in the field. The processes to be tested are divided into "Value-Added Storage Options" and "Non-value added Storage Options". The "Value-Added" class would be typically commercially developed first to recover fossil fuel fluids but have secondary value as storage sites for CO_2. The "Non-Value Added" would only be developed if there were an economic value to reduce CO_2 emissions to the atmosphere. These two classes of processes have the following storage engineering technologies.

- Value-Added Storage Options

  - Enhanced Oil Recovery (EOR): This technology, injection of CO_2 that dissolves in the oil lowering the viscosity and providing pressure maintenance, is at a mature stage for production of oil but needs to be re-engineered for storage.

  - Enhanced Gas Recovery (EGR): This technology, injection of CO_2 for pressure maintenance, has not been tested commercially, as typically gas reservoirs are depleted over 90% by primary production. Issues surround mixing of the CO_2 with the hydrocarbon gas and early breakthrough to the producing wells

  - Enhanced Coalbed Methane Recovery (ECBM): This technology is immature as is the CBM industry. Current wisdom would be to deplete the reservoir before injecting CO_2. Issues are swelling of the coal by sorption of CO_2 decreasing the permeability, rates of diffusion of gases to and from the coal matrix into the cleats and water production.

  - Acid Gas Injection (AGI): This technology was developed in the 1980's and is the injection and storage of acid gas (CO_2 and H_2S) into geological media to reduce H_2S emissions. Issues are the ultimate fate of the acid gas and the corrosion/cement deterioration of nearby wells.

  - Gas over Bitumen (GOB): The desire is to re-pressurize gas reservoirs, which have been depleted, to restore natural gas drive for bitumen production.

- Non-value Added Storage Options

  - Depleted Hydrocarbon Reservoirs: Depleted oil, gas and CBM reservoirs provide empty pore space that may be reoccupied by storage of CO_2.

- Saline Aquifers: Unique challenges are injection over original reservoir pressure for long period of time followed by decay to original pressures after injection ceases.

Key Programs and Projects

It is proposed that CANiSTORE will operate two major programs to foster research, development and deployment (see Appendix G for identification of specific technologies). The first program is:

➲ Research and Development

This program is further subdivided into two subprograms entitled Policy & Peformance and Science & Technology:

- Policy and Performance:

Regulation/Education/Outreach

Outreach is an extremely important activity that is primarily the role of government to facilitate the acceptance of geological storage as a safe and reliable option by the public and industry. This activity is conducted in close concert with the development of the legal/regulatory framework. The flow of technology development to piloting and commercial operations parallels the transfer of funding support of CANiSTORE from government to industry.

The notion of capturing and storing carbon dioxide and other greenhouse gases in geological media is relatively new, and many people are unaware of its role as a greenhouse gas reduction strategy. Increased education and awareness are needed to achieve acceptance of carbon sequestration by the general public, regulatory agencies, policy makers, and industry and thus enable future commercial deployments of advanced technology.

In concert with the CANiSTORE's R&D activities, the education/outreach program will seek to engage NGO's, federal, provincial, municipal and local environmental regulators to raise awareness of what the program is doing in this area, and the priority it places on systems that preserve human and ecosystem health. Successful outreach entails two-way communications, and the program will consider concerns voiced at outreach venues and continually assess the adequacy and focus of the technology development programs.

Risk/Performance Assessment

Risk models need to be established for the leakage of the CO_2 (slowly and rapidly) from the storage reservoir through breaks in the seals and along well bores both in the short (during the injection period) and in the long (over the storage period). Safety issues and verification strategies feed into the risk/performance assessment.

Life Cycle/Economics

The program will focus on the question "What is life cycle analysis in the context of geological storage" to analyze in the evaluation of GHG emissions throughout the full product or service system life cycle. Economic models have to evolve to handle environmental and health costs. The inclusion of income from emission trading and calculation of net CO_2 stored need to be incorporated in the economic models. Appendix C provides information on the elements required in the development of a integrated economic model for CO_2 capture and storage.

- Science and Technology

This component will be carried out by the universities and government research and technology transfer organizations, and will be aligned with industry needs and linked directly to specific piloting or demonstration projects or it will not be funded. Both piloting (i.e. field pilots) and commercial demonstration projects are to be initiated and operated by industry (In the case of geological storage, governments may have to be involved much higher up in the "S" curve than would be the case for "economic development" projects). The science and technology development areas are:

Regional Scale Geological and Hydrogeological Characterization

Geological and hydrogeological characterization for selected areas, as well as around the storage unit (reservoir, deep aquifer, coal bed) through detailed interpretation of geology, geochemistry, geomechanical and geothermal regimes, deep hydrogeology and shallow groundwater. This is the broader box that contains the storage unit and controls the migration of CO_2 if and when it migrates and/or leaks from the storage unit. Appendix A provides additional details concerning the evaluation of sedimentary basins in Canada for CO_2 storage.

Reservoir (Storage Unit) Characterization

Characterization of the reservoir: hydrocarbon reservoir, deep aquifer or coal bed. This is the primary container for the CO_2 and must be quantified in terms of heterogeneity in terms of permeability, pore space, reactive mineralogy and weaknesses in the primary seals as a function of pressure. Geological site characterization focuses on the storage reservoir through detailed interpretation of the geology, geochemistry, geomechanical, and deep hydrogeology. This is the box that contains the storage reservoir and sealing caprock.

Well Characterization

Identification of natural leakage paths, and in addition susceptibility to leakage through abandoned wells must be assessed. Independently, all aspects of injection and production wells and abandonment of wells must be improved, particularly abandonment if the wells are to survive for 1000 years or more.

Well Technology

A review of the past practices will be made with a view to the stability of the casing and cements, and bonding between the cement, formation and casing. New materials and procedures for abandonment are needed so that the wells will not leak over the long term.

Storage Engineering

This area includes both reservoir and storage engineering issues. It focuses on maximizing the storage potential and petroleum potential of the reservoir over the long term being cognizant of the economics.

Measurement, Monitoring and Verification

The aspects of technology that must be addressed are frequency of monitoring, spacing of tools, vertical depths of monitoring from the reservoir to the surface and development of new monitoring tools as well as safety and risk, standards and protocols. Monitoring technology will input into the regulatory framework. Appendix B provides specific details on the use of seismic and geochemical monitoring technologies in verification activities related to geological storage.

Pipelining and Surface Facilities

CO_2 pipelines exist as do CO_2 pumps. Focus would be on substitute materials to lower the costs.

Containment Engineering

Containment engineering is the assessment and design of the CO_2 trapping systems outside the storage reservoir.

Mitigation Engineering

Mitigation technologies are design to block CO_2 leaks from the storage reservoir, once they are discovered and to remediate damages.

➲ Pilot and Demonstration Projects

Two important elements of the Pilot and Demonstration Project program are a pilot project conducted through CANiSTORE and collaboration or liaisons with external projects. Acceleration from pilots to commercial demonstrations is assisted by utilization of the "The CO_2 Hub" (see Appendix D).

- Heartland Geological Storage Project

  The requirements sought for a CANiSTORE pilot location are:

  - A large industrial complex which has several types of CO_2 waste streams,
  - Overlies a range of geological storage reservoir types including CBM and saline aquifers, the portion of the sedimentary basin where the industrial complex is located is in a mature stage for CO_2 injection (i.e. depleted in oil and gas),
  - Easily accessible to oil and gas industry infrastructure, and to the oil and gas producers.

  Based on these conditions, it is proposed that the Heartland industrial area near Ft. Saskatchewan be chosen for the location of the geological storage pilot project.

Appendix E provides justification in support for the selection of this region for a geological storage pilot.

- External Project Liaisons

  Assist in organizing links and collaborative opportunities with other projects in Canada, and with organizations from other nations that will help advance the strategic research and development initiatives and the pilot project execution. Appendix F provides a draft framework for international project collaboration and scientific exchange.

Relationship between CANiSTORE Programs

Based on the significant role CANiSTORE is envisaged to perform in assisting in the development of a Geological Storage industry, it will be important that the organizational structure of CANiSTORE be sufficiently robust to effectively undertake the pilot projects and meet the commitments for leading the research and development programs. Figure 3 shows one possible structure for the "process flow" of a CANiSTORE pilot project. In general:

- Project is screened for accessibility through the geological surveys basin evaluation using regional and reservoir characterization. Industry would focus on the reservoir characterization while the geological surveys would assess the barriers and conduits to and for flow in the surrounding geological media.
- Site selection issues such as ownership, legal aspects, liability, and outreach are addressed. The oil and gas company who owns the property would normally become the operator of the pilot if the pilot receives final approval after the succeeding steps.
- CANISTORE would apply for experimental pilot status based on a preliminary scoping design.
- The format of the pilot design would be that required for submission to the regulatory agencies for granting of experimental status and would also serve as a document for board approval. During the design, there would be exchange between the technology development teams, the performance program teams and the pilot operating team in the following areas: wells, surface facilities, operating costs, management, CO_2 storage, pilot risks, monitoring, regional and reservoir characterization, CO_2 source, and injection/production performance.
- The outcome of the design would provide a pilot budget and quantify the pilot ranking against other candidates that were being evaluated by the Centre using the same process.
- Based on board approval after their review of the document, the final design and costing would be done before submitting to the regulatory agency for experimental status approval.
- Once regulatory approval is received, a tendering process for all aspects of the pilot will be made.
- Strategic alliances will be sought with oil field service suppliers to support the technology team as well as trying to optimize costs for the pilot.
- The pilot will then be built and commissioned.

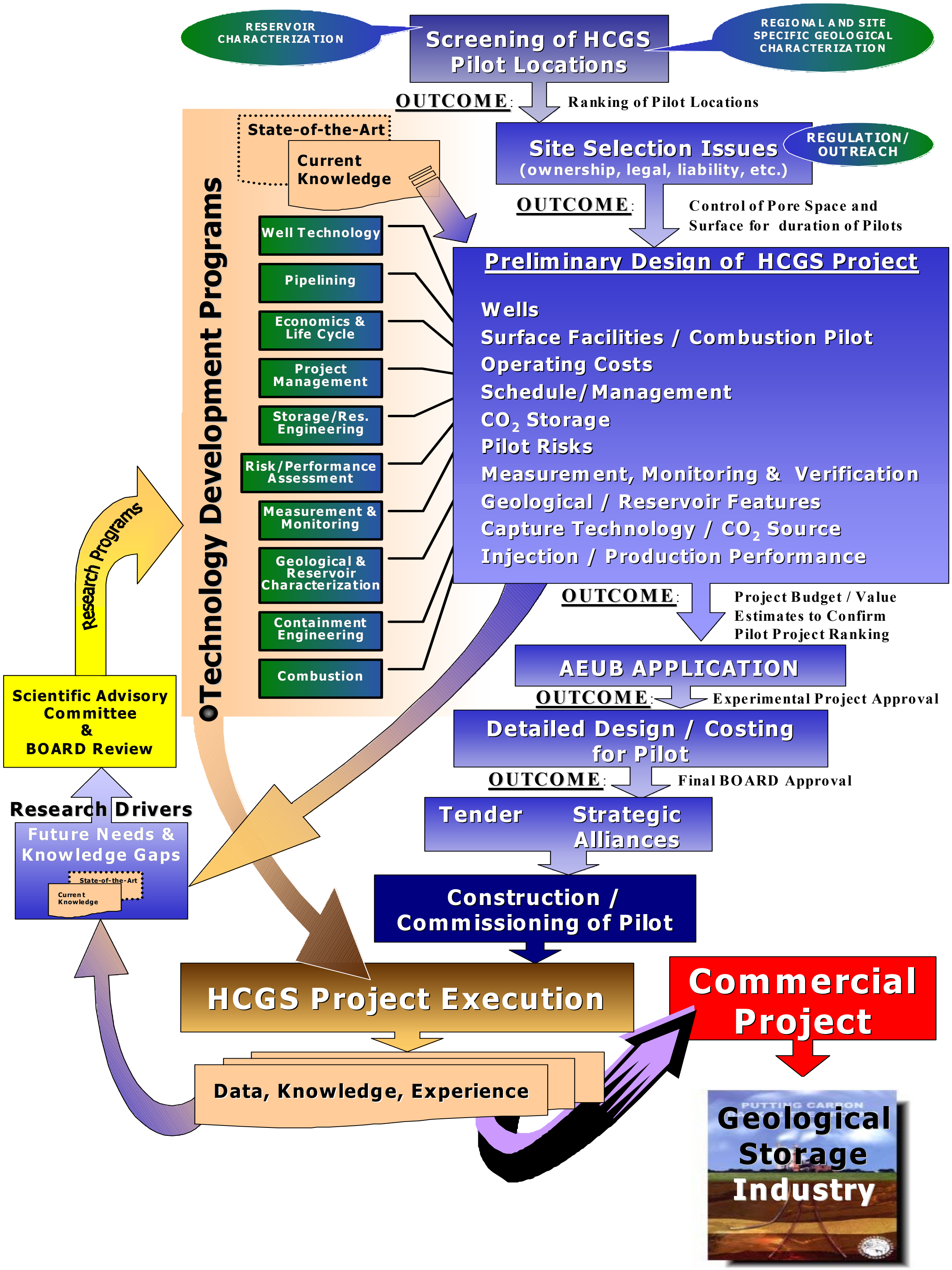

Figure 3: Organization elements in the operational structure of CANiSTORE

- During pilot execution, the technology development and performance program teams will be conducting measurements and doing assessments under the guidance of the operator.
- The pilot project can be rated successful based on two criteria, either:
    - A commercial success would lead to a commercial demonstration with or without the CANiSTORE's participation.
    - A technical success would lead to IP but because of the poor reservoir quality, the pilot would not be expanded. However, the technical success would produce data, knowledge and experience that would be used, in addition to identify future needs and knowledge gaps.
- Research drivers would allow the Scientific Advisory Committee to make recommendations both to the board and the managers of the Technology Development and Performance Programs for future emphasis and refinement of scoping criteria for future pilots.

Risk Management Plan

The largest risk facing the development of the CANiSTORE is government and industry support for geological storage. A financial plan needs to be developed and approved. This will be undertaken with full consultation with the Steering Committee. The process must also be amenable to variation in timeframe and future unforeseen changes in funding and general support for the CANiSTORE. Appendix H contains the elements of a financial plan both at high level, demonstration and pilot scales.

APPENDIX A - EVALUATION OF SEDIMENTARY BASINS IN CANADA FOR CO_2 STORAGE: A PROPOSED ROLE FOR THE FEDERAL AND PROVINCIAL GEOLOGICAL SURVEYS

By Stefan Bachu, Alberta Geological Survey, Alberta Energy and Utilities Board

Geological Storage of CO_2

The fundamental physicochemical mechanisms for CO_2 storage in underground geological media translate basically into the following means of CO_2 trapping:

- Volumetric, whereby pure-phase, undissolved CO_2 is trapped in a rock volume and cannot rise to the surface due to physical and/or hydrodynamic barriers. The storage volume can be provided by:
  - large man-made cavities, such as caverns and mines; or
  - the pore space present in geological media; if trapped in the pore space, CO_2 can be at saturations greater or less than the irreducible saturation; if the latter, the interfacial tension keeps the residual gas in place; if the former, pure CO_2 can be trapped
    1. in stratigraphic and structural traps in depleted oil and gas reservoirs and in aquifers (static accumulations), or
    2. as a migrating plume in large-scale flow systems (hydrodynamic trapping).
- In solution, whereby CO_2 is dissolved into fluids that saturate the pore space in geological media, such as formation water and reservoir oil.
- Adsorbed onto coal.
- Chemically bound as a mineral precipitate.

These means of CO_2 storage can occur in the following geological media:

- oil and gas reservoirs
- coal seams (sorption is the only potentially practical technique in coal seams and will not be a significant storage mechanism in the other classes of geological media)
- saline formations (deep aquifers saturated with brackish water or brine)
- other (i.e., salt caverns, sealed mines, etc.)

Assuming that there is no leakage from the system, the timeframe of CO_2 storage in underground geological media may vary from a minimum of several months for enhanced oil and gas recovery operations, including coalbed methane (where CO_2 is co-produced and recycled back into the formations), through hundreds to millions of years for other means, to permanently, as in the case of mineral precipitation. The geological media that provide the space and means for the underground geological storage of CO_2 are found in sedimentary basins, which happen to be the place where fossil-fuel resources were generated and have accumulated. Crystalline and metamorphic rocks, such as granite, on continental shields are not suitable for CO_2 storage because they lack the porosity and permeability needed for CO_2 injection, and because of their fractured nature. Volcanic areas and orogenic belts (mountains) are also unsuitable, mainly because they lack capacity and injectivity, and are unsafe due to the faults and fractures created during mountain-building events. For Canada this means that a large part of the country that is covered by the Rocky Mountains and by the Canadian Precambrian Shield is not suitable for CO_2 geological sequestration.

Suitability and Selection of Canada's Sedimentary Basins for CO_2 Storage

There are 68 sedimentary provinces in Canada, most of them distributed along Canada's shores. Only the Alberta and Williston basins, commonly known as the Western Canada Sedimentary Basin, form a large continental basin that is world-class in terms of hydrocarbon resources and production. Canada's sedimentary basins can be grouped into 12 groups based on type and geographic distribution (Figure A1) that are variously suited for CO_2 storage. Criteria for assessing basin suitability can be broadly classified into (Bachu, 2000, 2002, 2003):

- basin characteristics, such as tectonism, geology, and geothermal and hydrodynamic regimes (these are 'hard' criteria because they do not change);
- basin resources (hydrocarbons, coal, salt), maturity and infrastructure (these are 'semi-hard' criteria because they may change with new discoveries, technological advances and/or economic development); and
- societal, such as level of development, economy, public education and attitude (these are 'soft' criteria because they can change rapidly).

The Pacific basins in western Canada (Figure A1) are the least suitable for CO_2 storage and should generally be avoided because they are located in tectonically active areas, along subduction zones where the Pacific and Juan de Fuca oceanic plates move toward and dip beneath the North American continental plate. The potential for CO_2 leakage in these regions is significant, as shown by widespread gas leakage at macro and micro scales in Italy and Japan. Convergent intramontane basins in British Columbia are not favourable, mainly because of structure (faulting and folding). For both Pacific and intramontane basins, the safety of CO_2 storage may become an issue, with a significant potential and risk for either catastrophic escape or significant continuous leakage of CO_2 to the surface. Divergent basins on the rigid lithosphere (cratonic and Atlantic-type) are the most suitable for CO_2 storage as a result of their stability and favourable structure. The Williston and Hudson Bay basins, and all Atlantic and Arctic basins in Canada are of this type (Figure A1). Basins on the continental side of mountain-building orogens (foredeeps) are also favourable for CO_2 sequestration. In Canada these are the Alberta, Beaufort-Mackenzie and St. Lawrence basins (Figure A1).

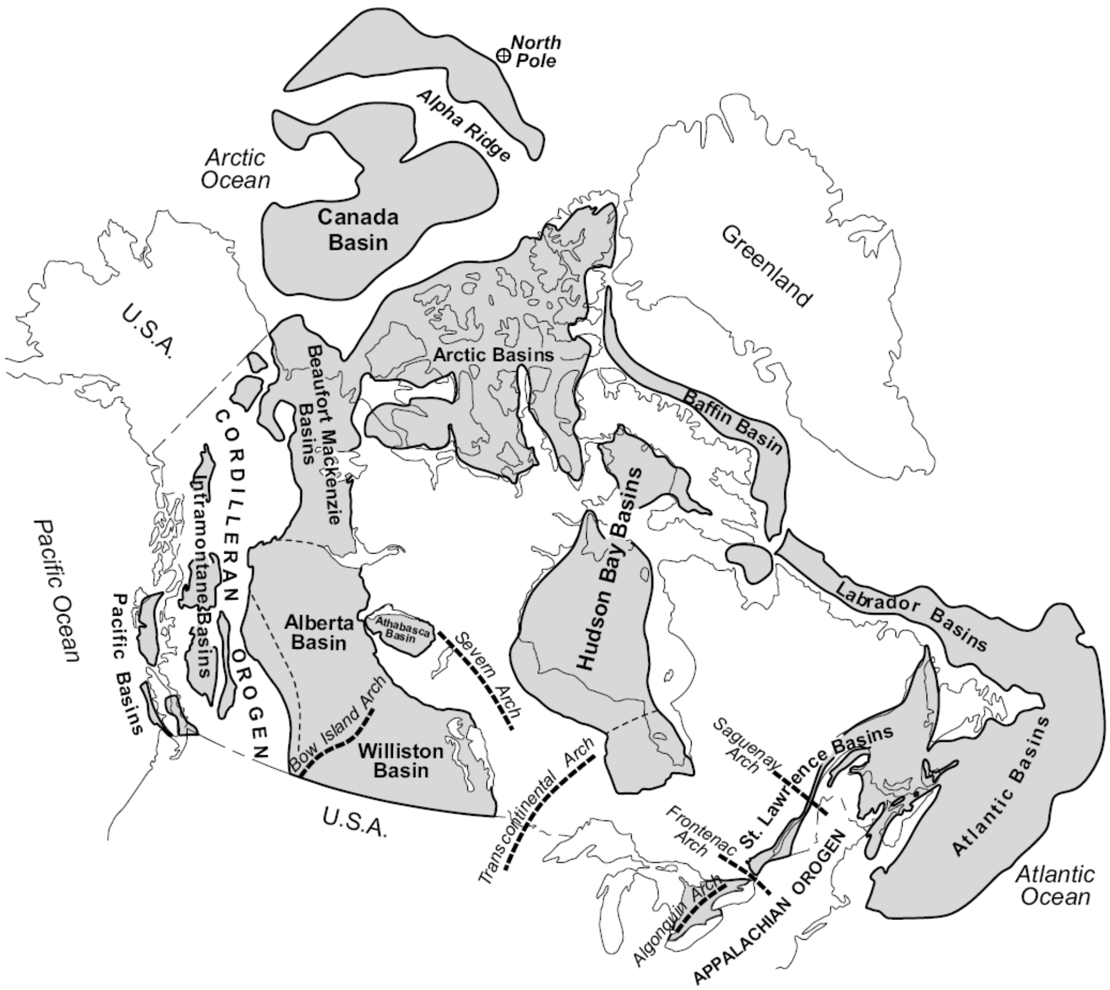

Figure A1: Distribution of Sedimentary Basins in Canada

The efficiency of CO_2 storage in geological media increases with increasing CO_2 density. Storage safety also increases with increasing density, inasmuch as buoyancy, which drives CO_2 upward migration, is stronger for a lighter fluid. Density increases significantly with depth while CO_2 is in gaseous phase, increases only slightly or plateaus after passing from the gaseous phase into the dense phase, and may even decrease with further increase in depth, depending on geothermal regime. Hence, if the CO_2 trapping mechanism is in pore space or a cavern, it should be stored as a dense fluid (liquid or supercritical) rather than as a gas, thus increasing the capacity and the safety of storage. Depending mainly on the geothermal regime in a basin, CO_2 reaches dense-fluid conditions at depths greater than 700 to 1000 m in cold basins and greater than 1000 to 1500 m in warm basins. If the CO_2 trapping mechanism is adsorption onto coal, then the optimal storage depth is between 300 and 800 m, although depths of up to 1500 m are also possible.

The pressure and hydrodynamic regimes of formation waters in a sedimentary basin are important in selecting sites for CO_2 storage. Injection of CO_2 into formations overpressured by compaction and/or hydrocarbon generation may raise technological and safety issues, thus making them generally unsuitable. Such overpressured formations are found mainly in the Beaufort and Atlantic basins.

Underpressured formations in foreland and intracratonic basins that underwent recent significant uplift and erosion, such as in the Alberta and Williston basins, are among the best suited for CO_2 storage because the inward flow of formation water driven by erosional rebound opposes the upward flow of CO_2 driven by buoyancy. Injection and storage of CO_2 in deep saline aquifers characterized by long-range, regional-scale flow systems ensure extremely long residence time (thousands to millions of years); hence, these are suitable for CO_2 hydrodynamic and mineral trapping.

On a regional scale, the storage formation should be capped by extensive confining units (shale, salt or anhydrite beds), to ensure CO_2 storage and prevent its escape into overlying, shallower units and ultimately to the surface. Thus, extensively faulted and fractured sedimentary basins or parts thereof, particularly in seismically active areas, are not good candidates for CO_2 storage, unless the faults and fractures are sealed (closed) and CO_2 injection will not open them.

The fossil-energy potential (hydrocarbon and coal) and exploration maturity of a basin constitute additional criteria for the selection of sites for geological CO_2 storage. In basins with limited or no known energy resources, there are no coal beds or oil and gas reservoirs for CO_2 storage, except possibly deep saline formations. On the other hand, energy production, and therefore CO_2 emissions, is very seldom associated with such basins. Immature basins with hydrocarbon potential should not be considered as prime targets for CO_2 storage because most of the hydrocarbon resources are still to be discovered; therefore, there is potential for their contamination as long as the discovered reservoirs are far from being depleted. Immature basins may become a target only if the value or need of storing CO_2 overrides the value of the undiscovered hydrocarbons. Mature sedimentary basins are prime targets for CO_2 storage because: 1) their characteristics are well known; 2) most of the hydrocarbon pools and/or coal beds have already been discovered and put on production; and 3) some reservoirs might be already depleted, nearing depletion, or abandoned as uneconomic. In addition, mature sedimentary basins may already have in place the infrastructure needed for CO_2 transportation and injection.

Finally, basin location (onshore or offshore), climate, accessibility and infrastructure reflect the variability in conditions for getting the captured anthropogenic CO_2 from source to the point of storage. These elements therefore provide additional criteria for the selection of sites for the underground storage of CO_2.

By and large, sedimentary basins that are proven hydrocarbon provinces have all the requisite elements for CO_2 storage. Poor CO_2-storage potential is exhibited by sedimentary basins that: 1) are thin (<1000 m), or 2) have poor reservoir and seal relationships, or 3) are highly faulted and fractured, or 4) are fold belts, or 5) have strongly discordant sequences, or 6) contain volcanogenic sediments, or 7) have undergone significant diagenesis.

Examination of sedimentary basins in Canada and application of these regional-scale and general site selection criteria using a parameterization and normalization method (Bachu, 2003) leads to a ranking of Canada's sedimentary basins in terms of suitability for CO_2 geological sequestration that shows that the Alberta and Williston basins are by far the best suited and with most potential for CO_2 storage (Table 1). Furthermore, the same methodology can be applied to various regions of a sedimentary basin, which is appropriate for large basins with significant variability like Alberta and Williston basins. In the case of the Alberta basin, the parameterization and normalization procedure confirms previous qualitative assessments that southwestern Alberta is the region with most potential and capacity, while northeastern Alberta is the least suited (Table 2).

	BASIN	RANK
1	PACIFIC BASINS	0.08
2	INTRAMONTANE BASINS	0.17
3	MACKENZIE & BEAUFORT BASINS	0.54
4	WCSB	0.95
5	CANADIAN ARCTIC ISLAND BASINS	0.27
6	EASTERN ARCTIC AND LABRADOR BASINS	0.13
7	HUDSON BAY BASINS	0.20
8	ATLANTIC SHELF BASINS	0.31
9	GULF OF ST. LAWRENCE BASINS	0.24
10	ST. LAWRENCE RIVER BASINS	0.33
11	SW ONTARTIO BASIN	0.51

Table 1. Ranking of Canada's sedimentary basins in terms of suitability for CO_2 geological sequestration (from Bachu, 2003). Scores are in absolute value.

	BASIN	RANK
1	NE Alberta	0.32
2	NW Alberta	0.40
3	SE Alberta	0.71
4	SW Alberta	1.00
5	Eastern Alberta	0.53

Table 2. Ranking of various regions in the Alberta basin in terms of suitability for CO_2 geological sequestration (from Bachu, 2003). Scores are in relative value to the most suitable region.

This cursory analysis indicates that the primary targets for CO_2 sequestration in Canada should be the Alberta and Williston basins (i.e., northeastern B.C., Alberta and Saskatchewan). Second-order targets should be basins in Nova Scotia and the shallow edge of the Williston basin in Manitoba. Third-order targets should be the sedimentary strata in southwestern Ontario and southern Quebec. The intramontane basins in B.C., although ranked lower because of size and possible faulting, may have significant potential for CO_2 storage in coal beds. Because of this they are a second-order target. Beaufort-Mackenzie basins, although likely of great potential, should be a third- or fourth-order target because they lack infrastructure and large CO_2 sources. However, if the gas resources in the Mackenzie Delta are developed, this situation may change.

Approach for the Evaluation of a Sedimentary Basin for Geological Storage of CO_2

A top-down approach to the evaluation of sedimentary basins or regions thereof for CO_2 geological sequestration, including the selection and monitoring of storage sites, is shown in Figure A2. Geological surveys have an important (major) role to play in the basin- and regional-scale suitability analysis, in the identification and characterization of potential storage sites, in their screening and selection, in the determination of ultimate and immediate storage capacity, and in site characterization. In addition, geological surveys have a secondary role to play in monitoring the storage site to determine the migration path and fate of the injected CO_2 plume.

The suitability of depleted oil and gas reservoirs for CO_2 storage varies widely. General criteria to judge whether a reservoir is a good candidate for CO_2 storage are: 1) sufficient reservoir volume allowing storage capacity without exceeding containment pressure constraints (overburden) and without requiring non-economic compression to high pressure levels; 2) satisfactory containment (upper and lower sealing cap-rock); 3) adequate permeability allowing injection but also production; and 4) limited sensitivity to reductions in permeability due to plugging of the near injector region and reservoir stress fluctuations. The low capacity of shallow reservoirs, where CO_2 would be in the gas phase, makes them uneconomic because of storage inefficiency. On the other hand, if a reservoir is too deep, it becomes uneconomic due to the large cost of compression and associated CO_2 emissions. The pressure window of 9 to 34.5 MPa has been recommended as being economic for CO_2 sequestration in depleted hydrocarbon reservoirs. At these pressures, CO_2 is very compressible and typically has a density of 400 to 800 kg/m^3.

Criteria for the selection of reservoirs for CO_2-flood EOR projects are different. For miscible applications, light, low-viscosity oils (25 to 48 ^{o}API) are preferred. The reservoir pressure should be higher than the minimum miscibility pressure (MMP) needed for achieving dynamic miscibility between reservoir oil and CO_2. The MMP, which is generally above 10 to 15 MPa, depends on the oil composition and gravity, and on reservoir temperature. Temperatures should be below 121^{o}C (250^{o}F). Immiscible drives are adequate for heavy- to medium-gravity oils with viscosity in the 100 to 1000 cp range (12 to 25 ^{o}API). Other preferred criteria for both types of flooding include thin pay, high dip, homogenous formation, low porosity times thickness, and low vertical permeability. For horizontal reservoirs, no natural water drive, no major gas cap and no major natural fractures are desired. Reservoir thickness, permeability and transmissibility are not critical factors. Recent studies suggest the following additional guidelines to select the most appropriate oil reservoir for CO_2 storage, depending on reservoir type: 1) a rather heterogeneous reservoir for gas-in-solution reservoirs, compartmentalized reservoirs and heavy oil reservoirs (around 0.966 g/cm^3); and 2) a rather homogeneous reservoir for reservoirs with good vertical compartmentalization, light-oil reservoirs (around 0.825 g/cm^3) and water-flooded reservoirs. The density difference (buoyancy) between the lighter CO_2 and the reservoir oil and water leads to gravity override at the top of the reservoir, particularly if the reservoir is relatively homogeneous and has high permeability, negatively affecting the CO_2 storage and oil recovery. Reservoir heterogeneity may have a positive effect because it may counteract the buoyancy effect by slowing down the rise of CO_2 to the top of the reservoir and forcing it to spread laterally, resulting in better vertical sweep efficiency.

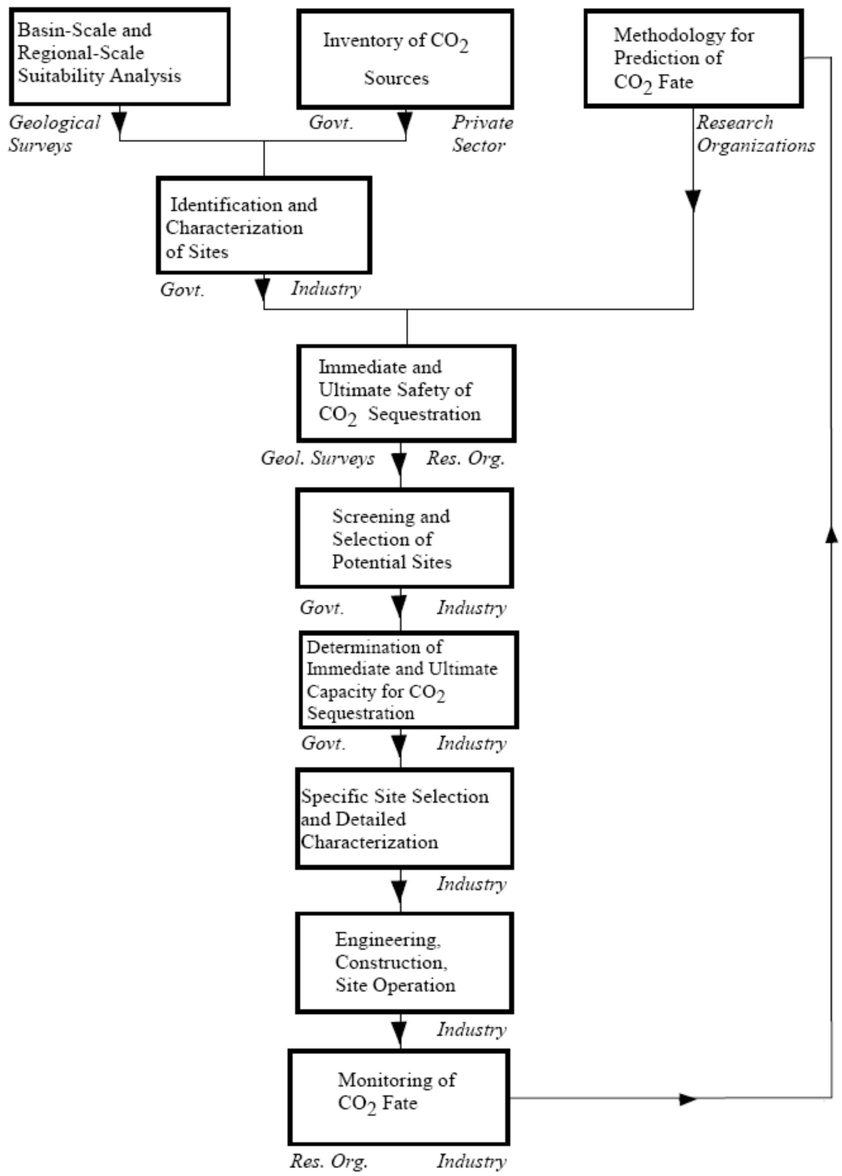

Figure A2: Flowchart for the Selection and Monitoring of CO_2 Geological Storage Sites

The following set of criteria has been proposed for the selection of sites for the CO_2 storage in coal beds and coalbed methane recovery: 1) the coal seam(s) should be laterally continuous and vertically isolated from surrounding strata, to prevent migration of CO_2; 2) concentrated coal deposits (few, thick seams) are better than stratigraphically dispersed (multiple) thin seams; 3) the reservoir should be minimally faulted and folded; 4) coal seams should be at depths of 300 to 1500 m; 5) the coal beds should have adequate permeability (at least 1 to 5 mD); 6) the coal should be preferably saturated with methane; and 7) the coal seam should preferably have low water saturation since it has to be dewatered before it can be used for CO_2 storage. Secondary reservoir criteria include coal rank, coal maceral composition (high vitrinite content preferred), low ash content (because ash does not adsorb methane), and gas composition.

The criteria for site selection for CO_2 storage in deep saline aquifers are fewer than for the other media, namely they are: 1) storage capacity (i.e., porosity); 2) injectivity (i.e., permeability); 3) the existence of physical and/or hydrodynamic barriers for CO_2 confinement; and 4) maintenance of the integrity of the confining aquitard or aquiclude (caprock) that should not be adversely affected by the pressure rise in the storage formation induced by the injection process, and by associated geomechanical and geochemical processes.

In addition to oil and gas reservoirs, coal beds and deep saline aquifers, CO_2 can be stored in salt caverns. Salt caverns created by solution mining are being used already in Canada for the storage of liquid natural gas and for the disposal of liquid and hazardous wastes, and they therefore be used for CO_2 storage in regions with high CO_2 emissions where other methods of storage are unavailable, such as in northeastern Alberta. Currently, single salt caverns are up to 500 000 m^3 in volume and can store fluids at pressures up to 80% of the fracturing threshold. Although a single cavern may not satisfy the needs of large CO_2 emitters, arrays of such caverns can be built in extensive and thick salt beds.

Central and common features for all means of CO_2 geological storage are the CO_2 phase, density and viscosity at in situ conditions, which determine and affect the capacity, efficiency and safety of storage through the interplay between available volume, and density and mobility difference between CO_2 and native fluids (oil, gas, formation water). Based on information routinely collected by the energy industry, the geological space can be transformed into the CO_2-space on a basin, regional or reservoir scale, to identify regions and sites suitable for CO_2 storage and to eliminate sites where the potential for CO_2 migration and/or leakage are enhanced (Bachu, 2002). Figure A3 shows the procedure to be used for such an evaluation.

Status of Evaluation Studies for CO_2 Geological Storage in Canada

Since 1998, the Alberta Geological Survey (AGS) of the Alberta Energy and Utilities Board has developed a vigorous sub-program in CO_2 geological storage with support from the Alberta Science and Research Authority (ASRA). At the same time, AGS has participated in a study by the Canadian Energy Research Institute (CERI), and has obtained the distribution and quality of all CO_2 sources in the Western Canada Sedimentary Basin (Alberta and Williston basins) with emissions greater than 100 kt/year each (Figure A4).

AGS has completed initially a broad study of the suitability of Alberta's subsurface for CO_2 geological storage that was extended to the whole of the Western Canada Sedimentary Basin (Figure A5) (Bachu and Stewart, 2002), followed by an evaluation of the potential for CO_2 storage in Alberta's oil and gas reservoirs, both at depletion and in enhanced oil recovery (Shaw and Bachu, 2002; Bachu and Shaw, 2003).

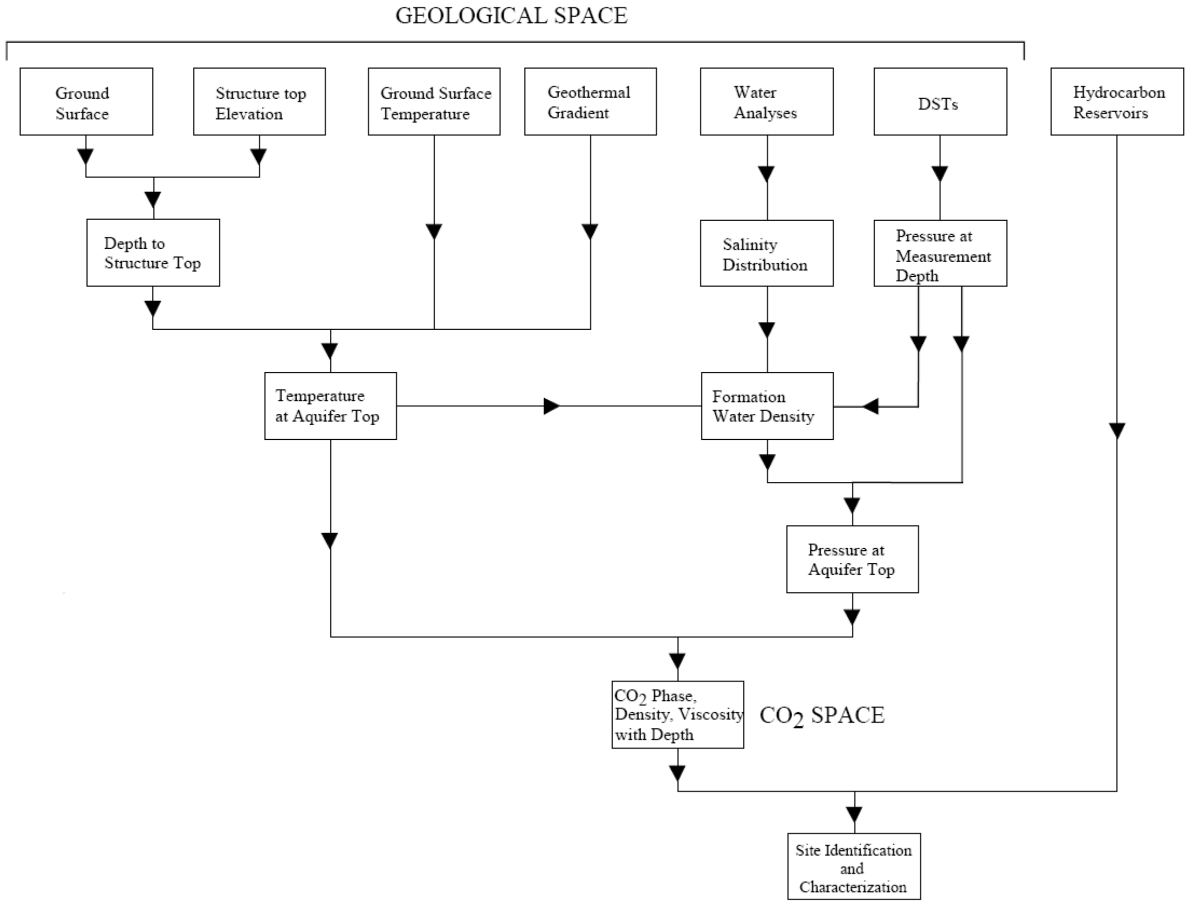

Figure A3: Flowchart of Data Processing for Identification of CO_2 Storage Sites based on Reservoir or Aquifer Characteristics

The ultimate theoretical potential for CO_2 storage in depleted oil and gas reservoirs in Alberta was estimated at 12 Gt CO_2, the great majority of it in depleted gas reservoirs. Of this, approximately 3 Gt capacity is in reservoirs with individual capacity greater than 1 Mt each that are located mostly in southwestern and western Alberta (Figure A6). With additional support from Natural Resources Canada (NRCan), this evaluation is being currently expanded to the other 3 provinces in the Western Canada Sedimentary Basin.

As part of a program on coalbed methane (CBM) potential and resources in Alberta AGS has identified the areas with the greatest CBM potential in Cretaceous and Tertiary strata in Alberta, and expanded the work to identify areas with high capacity and potential for CO_2 storage in coal beds (Figure A7).

Finally, AGS is conducting work for the identification, for each deep saline aquifer in the sedimentary succession in Alberta, of the regions that are suitable for CO_2 injection, based on the CO_2 phase and density at in-situ conditions, and on its solubility in formation water. The Viking Formation in the Alberta basin is being used for methodology development and testing (Figure A8).

Besides these basin and regional scale evaluations, the Alberta Geological Survey has conducted a compilation of the available information for all acid-gas injection operations in western Canada as of 2003, and now is in the process of conducting individual characterizations of the 7 clusters of acid-gas injection sites (Figure A9). The study of acid-gas injection operations is important because they are a commercial-scale analogue to CO_2 geological storage, and learnings from these will help in the development of a sound research and implementation program in geological storage of CO_2.

The Exploration and Geological Services Division of the Saskatchewan Department of Industry and Resources (SIR) has been involved in the characterization and monitoring of the Weyburn CO_2 flood EOR operation in southeastern Saskatchewan. The geology and hydrogeology of the entire sedimentary succession, from the Precambrian basement to the ground surface, has been characterized for an area 200x200 km^2 around the Weyburn operation. The current phase of research around the Weyburn project will end in 2004, but it is expected that there will be a continuation.

The Geological Survey Branch of the B.C. Ministry of Energy and Mines is conducting a program focused on the development of B.C. coalbed methane resources, which can be expanded to include CO_2 storage in coal beds.

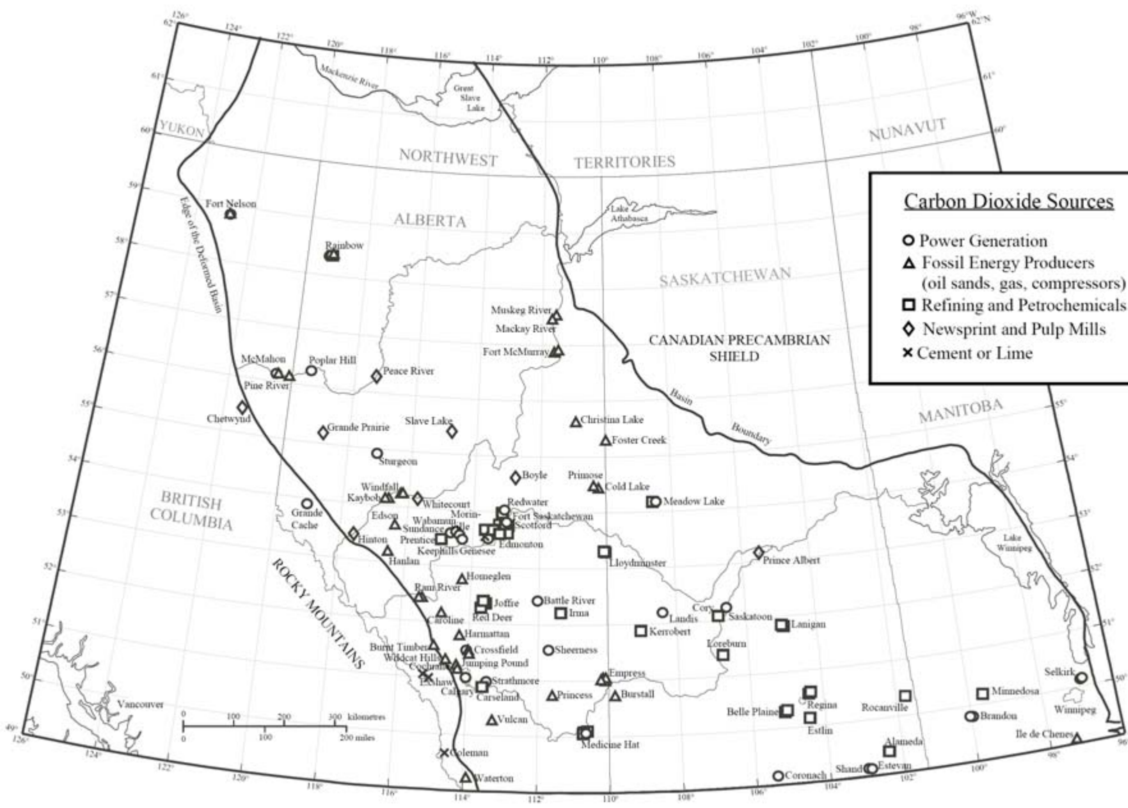

Figure A4: Location and Type of Major CO_2 Producers in the Western Canada Sedimentary Basin

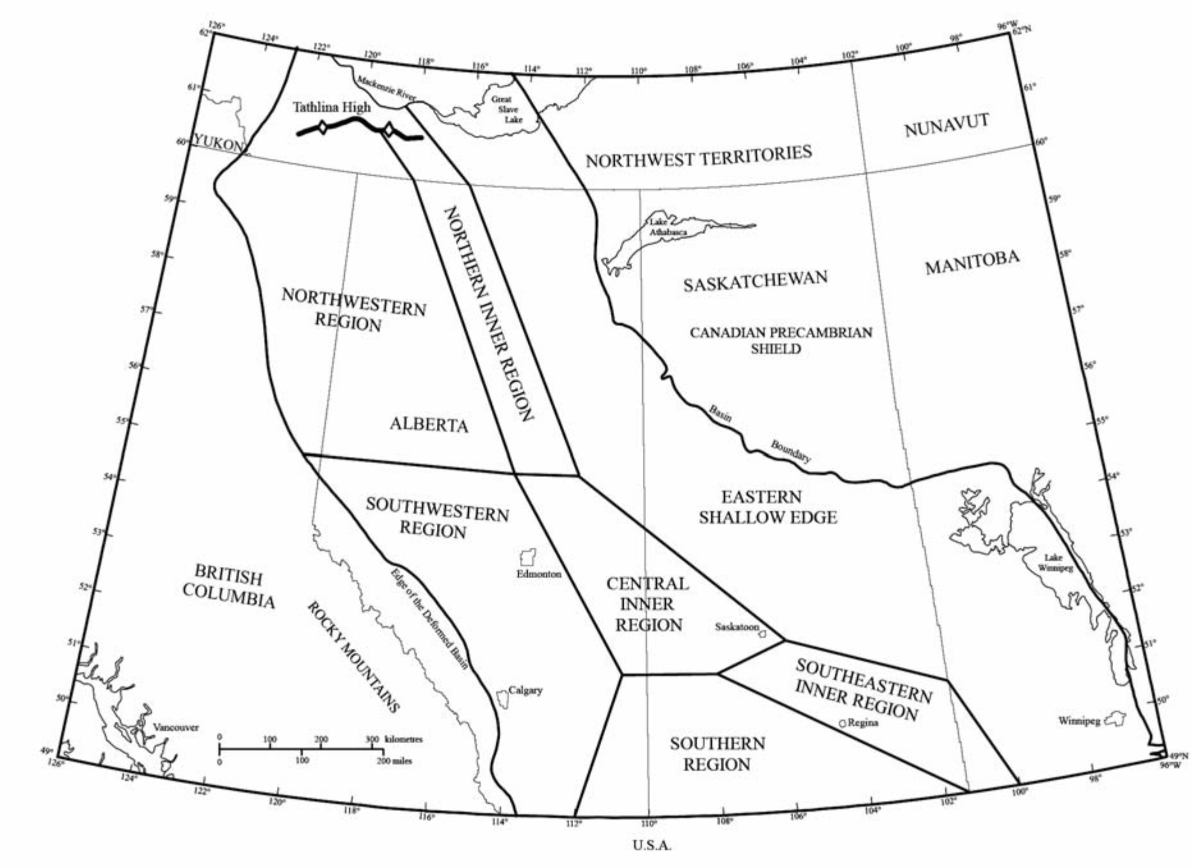

Figure A5: Suitability of the Western Canada Sedimentary Basin for CO_2 Storage in Geological Media

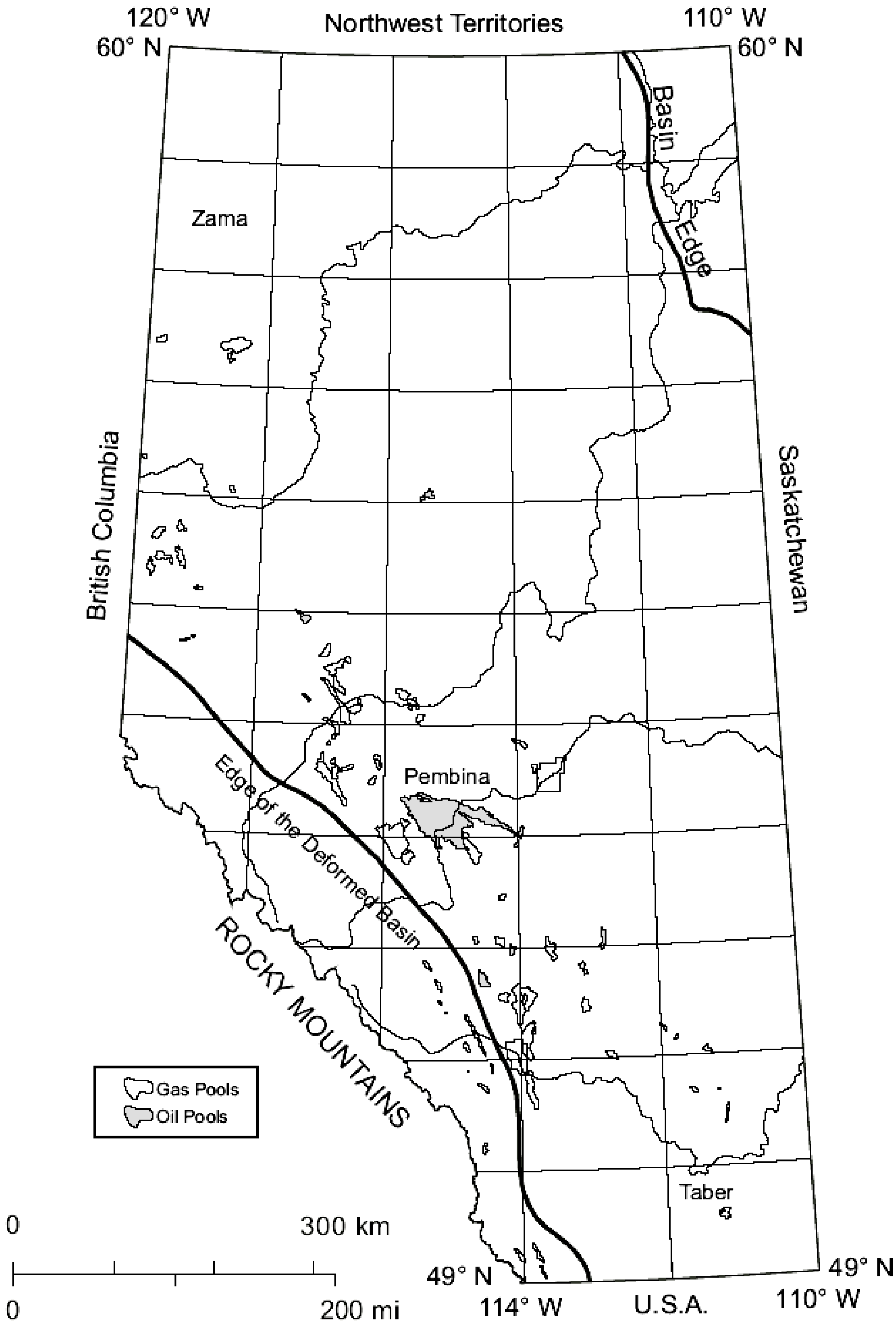

Figure A6: Location of Oil and Gas Reservoirs in Alberta with a CO_2 Storage Capacity greater than 1 Mt each

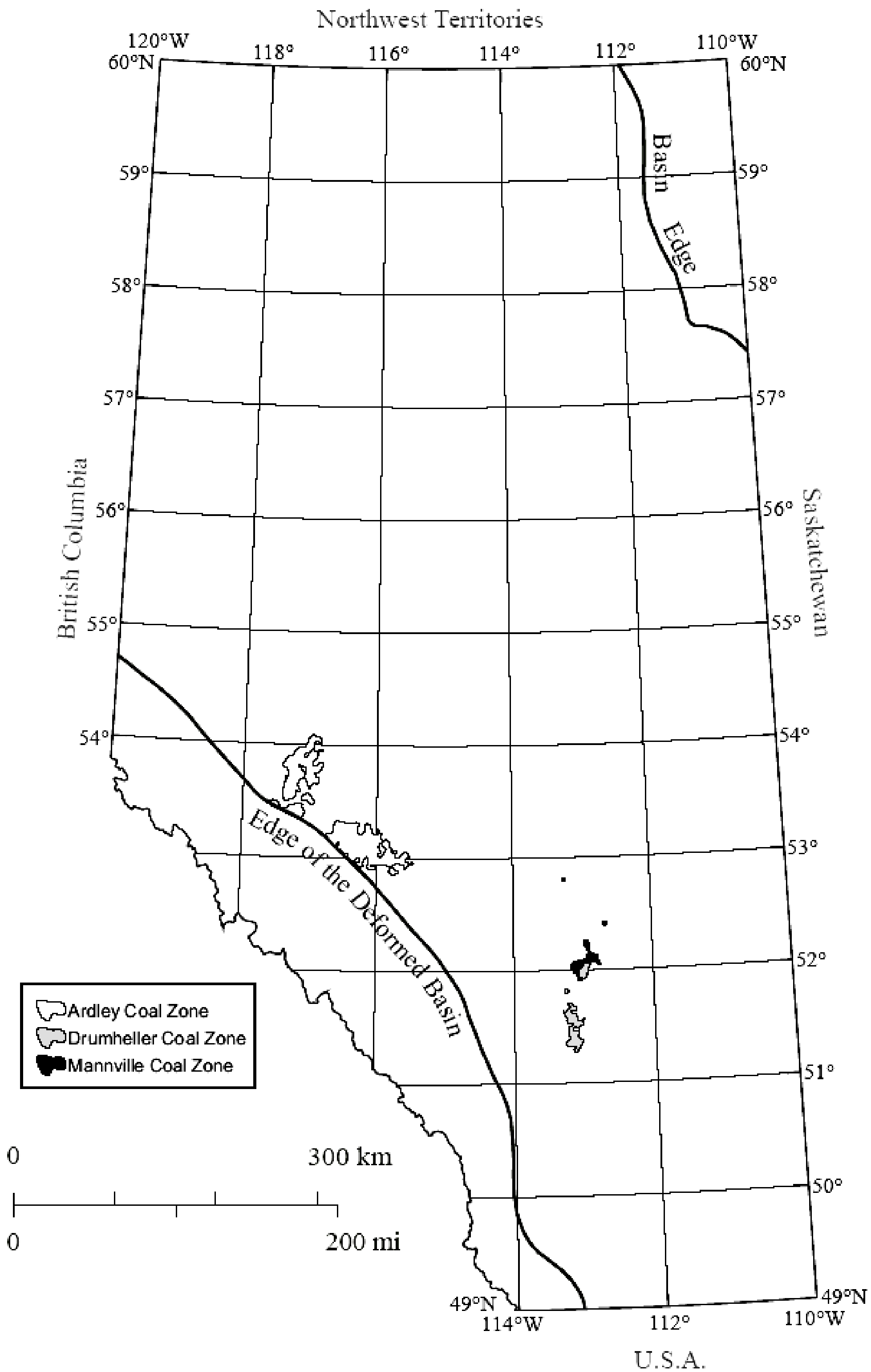

Figure A7: Location of Coal Fields with High Potential for CO_2 Storage in Alberta

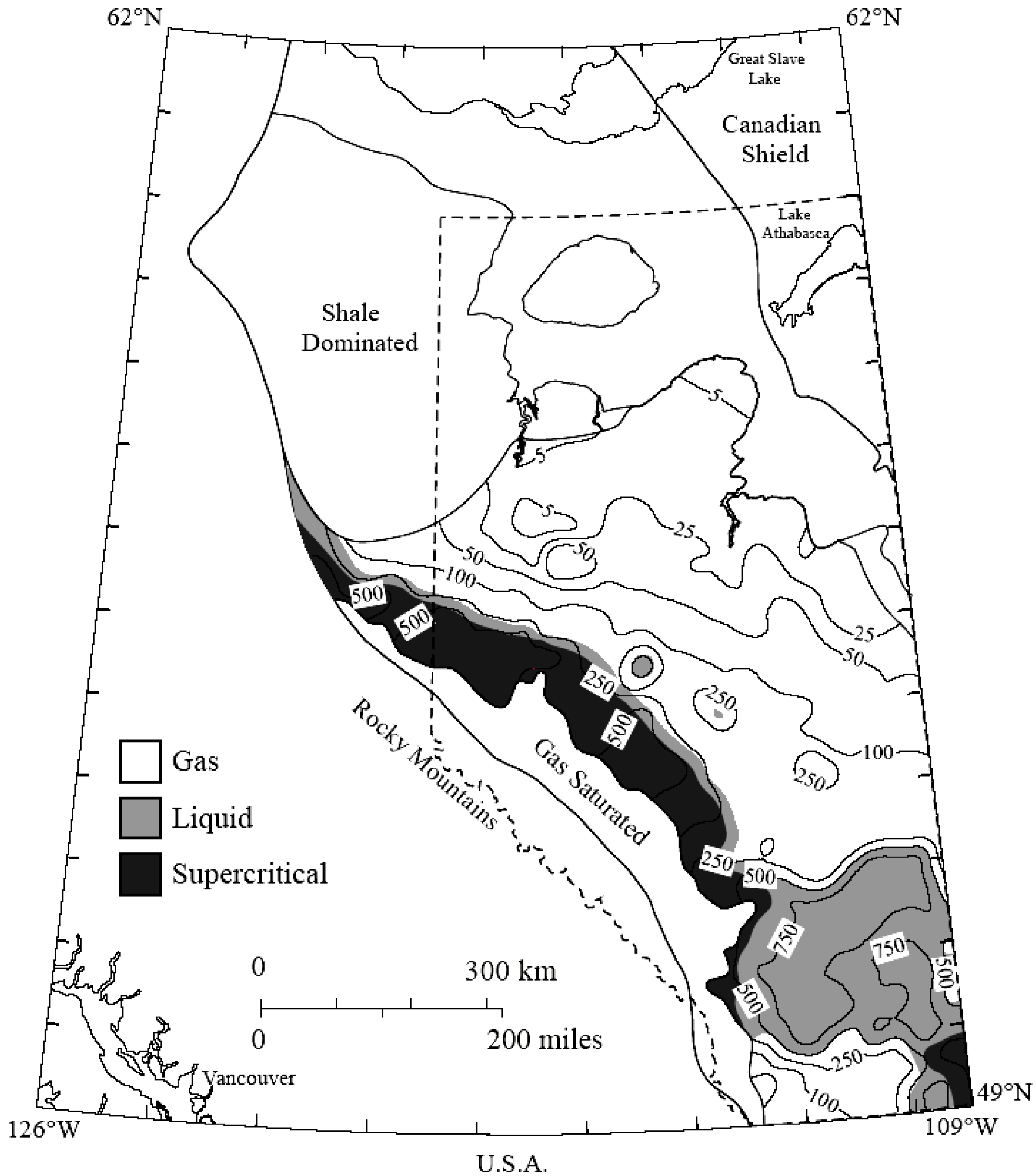

Figure A8: Carbon Dioxide Phase and Density at the top of the Viking Formation in the Alberta Basin

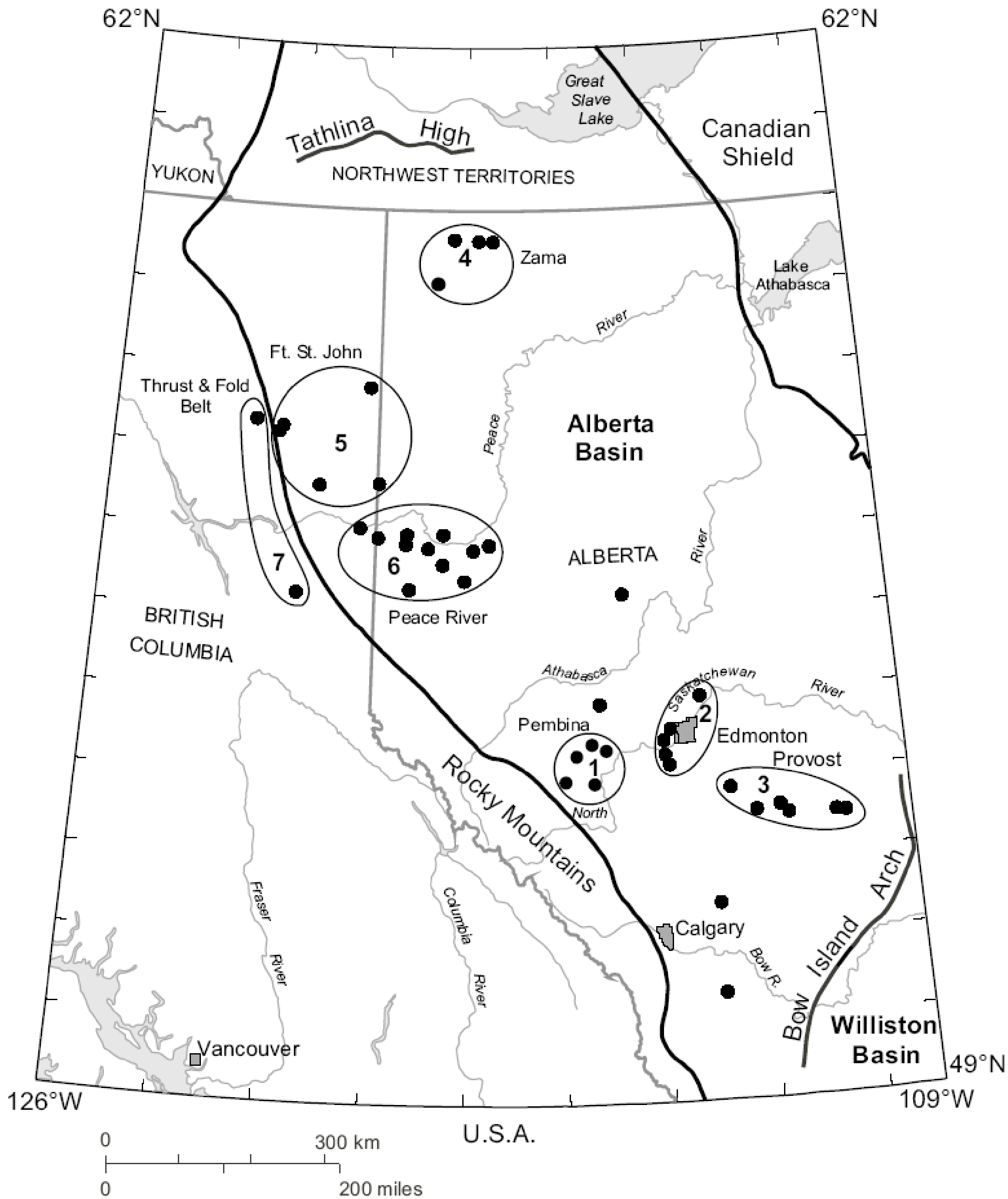

Figure A9: Location of Acid Gas Injection Sites in western Canada

Proposed Work for Evaluation Studies for CO_2 Geological Storage in Canada

The approach and methodology developed or in development at the Alberta Geological Survey can and should be applied for the detailed evaluation, formation by formation, of all the units in the sedimentary succession in the Alberta and Williston basins, and to other basins in Canada. Alberta Geological Survey should lead the effort in basin evaluation for CO_2 geological sequestration because Alberta has by far the largest storage capacity, large-scale implementation will likely occur in Alberta first (notwithstanding the Weyburn project in Saskatchewan), and because AGS has already completed significant methodology development and assessment. The Alberta Geological Survey will transfer knowledge and methodology to other geological surveys in Canada and will guide and lead the process of basin evaluation, and identification and selection of sites for CO_2 geological storage, including determination of the immediate and ultimate capacity of these sites.

In addition, the Alberta Geological Survey will directly conduct, participate and be involved in all work on CO_2 geological storage in Alberta that requires:

- geographic and stratigraphic evaluation for suitability of CO_2 storage;
- identification and characterization of potential storage sites in various geological media (hydrocarbon reservoirs, coal beds, deep saline aquifers, salt beds);
- determination of immediate and ultimate practical capacity for CO_2 storage at these sites;
- evaluation of the potential for CO_2 migration and/or leakage, and of storage safety;
- screening and selection of sites for implementation of CO_2 geological storage;
- detailed site characterization; and
- monitoring the evolution and fate of the CO_2 plume.

Other geological surveys in Canada should be involved at similar levels in projects and activities taking place in their respective areas of jurisdiction. Notwithstanding primacy in area of jurisdiction, geological surveys should work in collaboration, particularly in those basins or parts thereof that straddle provincial and territorial boundaries.

The proposed work has two components, evaluation and site characterization.

1. Basin evaluation

   The basin evaluation component is by and large predictable and can be planned for. It involves the evaluation of Canada's sedimentary basins for CO_2 storage, identification and selection of potential storage sites, and estimation of their capacity.

   It is proposed to build on work already completed at the Alberta Geological Survey, and execute and complete the work by 2008, the year when Canada must start proving that it is meeting its target according to the Kyoto Protocol. It is assumed that work will commence in FY 2004-2005 and end in FY 2007-2008.

Year I

- detailed evaluation and screening of Canada's sedimentary basins (beyond the broad analysis of Bachu, 2003), with the aim of identifying specifically what basins or parts thereof in Canada will be considered for CO_2 geological storage in the 2008-20025 timeframe;
- completion of the evaluation of the practical CO_2 storage capacity in oil and gas reservoirs in the Alberta and Williston basins (from B.C. to Manitoba), and identification of large-capacity reservoirs;
- completion of the evaluation of the practical CO_2 storage capacity in coal beds in the Alberta and Williston basins, and identification of target coal zones and areas;

Year II

- basin-scale evaluation of sedimentary basins in Nova Scotia;
- completion of stratigraphic evaluation (unit by unit) and capacity estimation for deep sedimentary formations in the Triassic-Tertiary siliciclastic succession in the Alberta and Williston basins;

Year III

- basin-scale evaluation of sedimentary basins in southwestern Ontario and southern Quebec;
- detailed evaluation and capacity estimation for sedimentary basins in Nova Scotia;
- completion of stratigraphic evaluation (unit by unit) and capacity estimation for deep sedimentary formations in the Devonian and Mississippian carbonate succession in the Alberta and Williston basins;

Year IV

- basin-scale evaluation of other sedimentary basins in Canada that may have CO_2 storage potential toward the later part of the period 2008-20025;
- detailed evaluation and capacity estimation for sedimentary basins in southwestern Ontario and southern Quebec;
- completion of stratigraphic evaluation (unit by unit) and capacity estimation for deep sedimentary formations in the Cambrian-to-Silurian succession in the Alberta and Williston basins;

2. Site characterization

This work component involves the regional-to-site scale characterization of CO_2 storage sites that have actually been selected for implementation and monitoring. Given the nature of the site selection process and the industry lead in selecting sites that are economically viable, it is difficult to predict the level of effort that will be required. While the Weyburn project currently has a 4-year characterization and monitoring program that that runs into millions of dollars, it is envisaged that this component will be on a reduced scale for other implementation sites.

Work will be executed as CO_2 storage sites are selected and implementation proceeds. It is most likely that in the next four years these sites will be mostly in Alberta, maybe a few in Saskatchewan in addition to the Weyburn and Midale EOR projects, and possibly in northeastern B.C., particularly if it is in conjunction with coalbed methane production. Sites that will likely become operational in this timeframe will most likely be in relation with enhanced oil or gas recovery, although it is possible that one major energy producer may start a "dry" storage scheme (not associated with oil or gas recovery).

Products

The proposed work will result in data, information and knowledge, notwithstanding trained expertise, that should become public through:

- reports and geological survey publications;
- maps at various scales and for various sedimentary units;
- databases
- web-based displays;
- journal articles and conference presentations.

These products should provide support to decision makers in government and industry for the implementation of CO_2 geological storage in Canada.

Expertise, Staffing and Organization

The proposed work in the evaluation of Canada's potential for CO_2 geological storage and the selection and characterization of potential sites requires a wide range of expertise and skills, mainly in the following areas:

- carbonate and siliciclastics geology
- coal geology and petrology
- geochemistry
- hydrogeology
- geothermics
- geomechanics
- reservoir engineering
- thermodynamics
- numerical modeling
- geographic information systems (GIS)
- database management
- software development

Geological surveys and research organizations do not necessarily have this expertise and set of skills, particularly as a result of last decade's budgetary reductions and restrictions at all levels of government. It may be necessary to form a core group centered in the region with the most potential, presumably Alberta, which will support evaluation and characterization activities all over Canada.

Such activities will still be conducted under the leadership of the designated organization in the respective jurisdiction. The core group may be affiliated directly with the Network of Innovation on CO_2 Capture and Storage.

Budget and Funding

Given the nature of the proposed work, the budget has to be split also along the lines of basin-scale evaluation and site characterization.

1. Basin evaluation

It is estimated that an annual budget of $300,000 is needed to complete the proposed work. If new staff has to be hired, the budget will be accordingly higher. The proposed work should be supported largely from public funds since it involves evaluation and analysis at a scale larger than the lease and/or reservoir scale that individual companies are interested in.

Very little revenue is expected to be realized from the sale of the reports and maps that will be produced as a result of this effort. The value of the work resides in the production and dissemination of data and knowledge needed by industry and governments for decision-making, and not in the sale value of the reports and associated maps. Only the cost of reproduction and dissemination will likely be recovered.

2. Site characterization

The budget for this work component can't be estimated because it is highly dependent on the selected site(s), location, stratigraphic position, available data, and other factors. It will have to be estimated on a case-by-case basis. As an order of magnitude, recent experience with the characterization of acid gas injection sites in western Canada indicates that the cost will be of the order of a few hundred thousand dollars per site.

Given the nature of the work and the very high potential for learning from site characterization studies, this work should also be supported, at least partially, from public funds. Only certain elements of the detailed site characterization should be supported by private companies with a direct interest in the site(s) being characterized, by allowing access to confidential and/or in-house data and information, and through other in-kind contributions. On the other hand, given the long-term nature of the CO_2 storage operations, long after cessation of injection and likely beyond the life of private companies, governments may institute a general levy on industry that will support these activities.

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APPENDIX B - GEOCHEMICAL AND SEISMIC MONITORING FOR VERIFICATION OF THE GEOLOGICAL STORAGE OF GREENHOUSE GASES

By Don Lawton and Bernard Mayer, University of Calgary with additions by Andrew Beaton, Alberta Geological Survey and Bill Gunter, Alberta Research Council

Monitoring objectives

The objectives of the proposed geochemical and geophysical monitoring program are to trace fluids and injected CO_2 (or acid gas) during a CO_2 storage project. The example discussed here is for a shallow Enhanced Coalbed Methane (ECBM) project (400 metres) but the program could easily be modified for other types of storage projects (e.g. EOR, depleted oil and gas reservoirs and aquifers). The program is designed to describe the fate of the injected CO_2 in the subsurface, verify storage of CO_2, and to evaluate the source of produced waters and impact of these produced waters and gases on aquifers in the study area. The program will provide information both on the efficiency of an enhanced coal bed methane (ECBM) project and its environmental impact. This information will be equally important to producers, regulatory government agencies and the public at large.

The verification of CO_2 storage is critically important because the public must be assured that the gases have been removed permanently from the surface environment. CO_2 storage is attractive for Canada since a large percentage of our CO_2 emissions comes from fixed-point sources such as power plants and petroleum processing facilities. If these emissions are captured and delivered to a storage site, they will never be released into the atmosphere. However, merely injecting gases into a reservoir does not guarantee that they will stay there. The gas could leak back to the surface or into valuable aquifers through a variety of mechanisms. Integrated seismic imaging and geochemical sampling and analysis programs are technologies that can document the motion of the injected gases and detect leakage from the storage horizon. In Figures B1 and B2, shallow and deep monitoring wells are shown within the injection-recovery pattern. Similar aquifer monitoring wells could be located farther away. The areas of Figure B2 also outline the footprint of time-lapse surface seismic monitoring surveys. The dimensions of the box are 1.5 times the depth to the injection level. Time-lapse Vertical seismic profiles would be run in the gas injection well, preferably during the surface seismic phase.

Individual project components designed to provide stand-alone information, which are essential to achieve the above-described objectives, are discussed below. Together, these components describe comprehensively the acid gas storage reservoir, surrounding rock and soil, and shallow and deep aquifers prior to, and after CO_2 (or acid gas) injection.

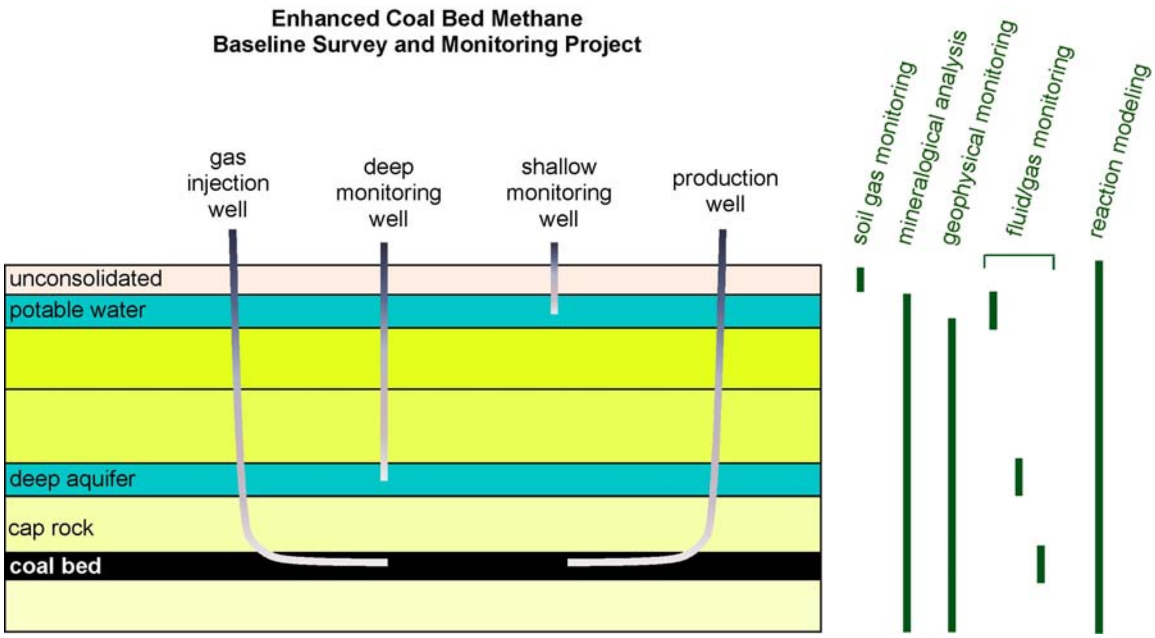

Figure B1. Cross section showing simplified relationships between the coal bed, rock units, soil, and aquifers. Vertical lines on the right correspond to depth intervals over which recommended analytical surveys are typically conducted.

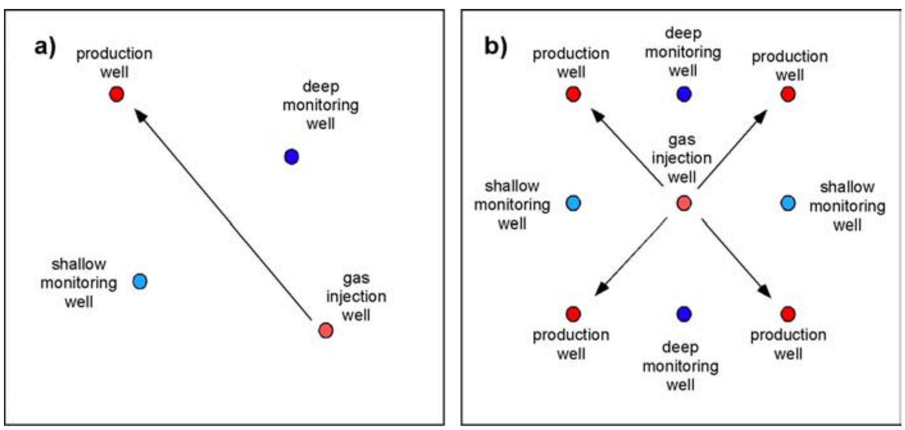

Figure B2. Plan view examples of (a) 1+ 1 and (b) 1+4 patterns of injection and recovery of ECBM.

Considerations for Geophysical Monitoring

Repeated surface multi-component (3C-3D) reflection seismic surveys are proposed at the CBM site as well as vertical seismic profiles (VSP) at the injector well. The objectives of these surveys are to image the coal zone to provide an accurate depth model of the coals in the survey area, and to detect lateral facies changes in the coals that may inhibit water or gas flow. In addition, a limited number (~6) geophones will be installed permanently in shallow observation wells to enable passive seismic monitoring to be undertaken. Repeated surface seismic and VSP surveys will be undertaken to address:

1. Seismic imaging of the dewatered zone – to monitor the dewatering process and track lateral and vertical extent of the dewatered zone.
2. Seismic imaging of the CO_2 plume – to monitor and track the plume within the coal zone and to optimize injection rates.
3. Seismic verification of CO_2 capture within the coals – to ensure that there is no significant leakage of CO_2 out of the coal zone, particularly into overlying strata that may yield pathways to the surface.

In the proposed CBM experiment, it is anticipated that the bulk elastic properties of the coal zone will change with dewatering of the coals, and that additional changes will also occur with CO_2 flooding. Changes, particularly in density and velocity in turn affect the amplitude and travel times of reflected seismic waves. Thus, a baseline survey, conducted prior to any CO_2 injection, will be compared to a survey conducted after a set period of injection to monitor the effects of gas on the reservoir. The magnitude of the change in seismic properties is dependent on the elastic properties of the host sediments. Poorly consolidated rocks, rocks with open fractures, and rocks under low overburden pressure will be those with seismic properties most affected by injection or production.

Seismic images taken at various stages of the program will be compared to delineate the dewatered zone and to track the motion of the subsurface CO_2 plume. This comparison of seismic images from repeated seismic surveys is known as time-lapse imaging and is an emerging methodology for the monitoring of subsurface reservoirs. In addition to verification of storage, such monitoring may also enable the intelligent selection of additional injection and production wells to optimize CBM production. Individual surface seismic and vertical seismic surveys are planned during the following stages of the program:

a. Phase 1 – baseline survey
b. Phase 2 – after dewatering
c. Phase 3 – after initial CO_2 flood (e.g. after 3 months)
d. Phase 4 – after CO_2 breakthrough at producing well(s).

Tiltmeter Surveys

In conjunction with the seismic programs, tiltmeter surveys are proposed to monitor of subsidence or dilation caused by production or injection of gases. Fracture systems (cleats) in coals may control permeability trends and opening or closing of cleats during injection or production phases may result in volumetric changes that are measurable in near-surface borehole-mounted tiltmeters. Tiltmeter responses, coupled with passive seismic programs that may detect dynamic cleat behaviour, may provide information on permeability trends in the reservoir that will affect storage dynamics and capacity.

Considerations for Geochemical monitoring of produced fluids

It is essential that the chemistry of the CBM gas and any produced fluids and the chemistry of deep aquifers be ascertained prior to acid gas injection (termed *Baseline*), probably during the dewatering phase. By doing so, comparisons between pre- and post-injection fluids and gases allow observations and calculations to be made as to the degree and speed of reaction between rock, liquids, and gases.

Injection and production wells will be monitored for liquid and gas fluxes and compositions (Figures B1 and B2).

Monitoring parameters for gases: CO_2, CH_4, H_2S, N_2, O_2, etc., $\delta^{13}C_{CO2}$, $\delta^{13}C_{CH4}$, $\delta^{34}S_{H2S}$

Frequency of sampling: at least monthly

Number of samples per annum: for 1+1 pad: 24 samples per year

for 1+4 pad: 60 samples per year

Monitoring parameters for fluids: alkalinity, anions, cations, etc. $\delta^{2}H$, $\delta^{18}O$, $\delta^{13}C_{DIC}$, $\delta^{34}S_{sulfate}$

Frequency of sampling: once a month

Number of samples per annum: for 1+1 pad: 12 samples per year

for 1+4 pad: 60 samples per year

Geochemical Monitoring of Shallow and Deep Aquifers

It is very important to ensure that the potable water aquifers in the region around the CBM gas wells do not become contaminated with any produced waters. To accomplish this, water quality monitoring must be in place before CBM production begins. This would involve determining the number and depths of the potable water aquifers. Water wells would be used as available. In addition, aquifer communication must be ascertained and nested standpipes for sampling water and determining aquifer hydraulic coefficients must be installed. Each pipe would go to a potable water aquifer and from these water samples will be regularly obtained. The samples are analyzed for their chemical and isotopic composition in order to monitor for potential changes in water quality. Similar monitoring programs are suggested for deep aquifers in case that water samples can be obtained.

Monitoring parameters for fluids: alkalinity, anions, cations, etc. $\delta^{2}H$, $\delta^{18}O$, $\delta^{13}C_{DIC}$, $\delta^{34}S_{sulfate}$

Frequency of sampling: circa 3 times per year

Number of samples per annum: circa 100 samples per year (depends on the number of wells and the number of aquifers)

Soil Gas Survey

As a "last line" monitoring method, subtle changes and anomalous acid gas concentrations in soil gas, particularly in the vicinity of wells can be monitored in the event of acid gas leakage from the coal bed and overlying strata. This method is also seen as a valuable tool in establishing public support.

Monitoring parameters for gases: CO_2, CH_4, H_2S and $\delta^{13}C_{CO2}$, $\delta^{13}C_{CH4}$, $\delta^{34}S_{H2S}$

Frequency of sampling: concentrations frequently, isotopic compositions less frequently

Number of samples per annum:	circa 50; note that special sampling containers must be purchased or constructed for transport of soil gases to the laboratory; this will be a significant cost factor of the soil gas monitoring program.

Mineralogical Analysis

Establishing the mineralogy, whole rock compositions and reactive mineral suite for rocks that surround (esp. overly) the injection site is important input information for reaction modelers and the reliability of quantitative storage information for injected gas (e.g. CO_2). Approximately 50 samples from strata immediately below and above the coal seam, and approximately 50 samples from strata up-section (towards the surface) will be collected. Whole-rock analyses (XRD, XRF, ICP-MS) in conjunction with mineralogical work (microscopy, and Electron Probe Microanalysis) will be used to constrain quantitative modal mineralogy for each sample. These analyses are essential to determine the potential for long-term geological storage of injected CO_2.

Fluid Phase Equilibria Monitoring and Prediction

Evaluating the fate of injected supercritical CO_2 during an enhanced coal bed methane project requires the use and evaluation of P-T-X data and proper equations of state for mixtures of phases present in the reservoirs. All present phases may be simplified to CO_2-H_2S-CH_4-H_2-NaCl systems. Such control allows solubility calculations, which yield amounts of "absorbed CO_2"in formation gases/fluids during the various periods of injection. Furthermore, a critical evaluation of experimental solubility data for non-ideal CO_2-CH_4 mixtures at reservoirs P-T conditions is needed in order to determine proper and profitable injection pressures.

Considerations for the Geological Baseline

Create a geological model of the strata associated with the Ardley Coal Zone in the ECBM site to evaluate coal continuity and thickness, seals on top of the coal and aquifers above the coal. Within the site area, the nature of interbedded lithology is variable. Sand channels may encounter or come very close to the seams of interest. This may result in 1) disruption of the shale cap seal on top of the coal seam, and 2) possibly introduce water into the coal seam if the sands are aquifers which would also allow the injected CO_2 to escape. It is also noted that the Ardley coal zone will split and coalesce over relatively short intervals, and therefore the coal seam should be modeled within the study area.

Geophysical Monitoring Plan

Seismic Monitoring

There is an opportunity to test three geophysical technologies at the pilot site. The University of Alberta wishes to do in-situ passive seismic monitoring in the CBM reservoir to listen to the sonic responses of the reservoir during injection and production. The University of Calgary wishes to do the more conventional timelapse 3-D seismic acquisition from the surface as well as vertical seismic profiles and intepret these data to assist in mapping the continuity of the coal reservoir and 4-D seismic to detect fluid movement and cleat opening. The Lawrence Berkeley National Laboratories wishes to do in-situ cross-well seismic data collection in the reservoir to monitor changes in the reservoir between two wells. These seismic monitoring techniques will be evaluated to determine if they are sensitive enough to aid in controlling the injection process, to track reservoir storage processes, to assess conformance (e.g. confinement/leakage) and to verify reservoir simulation predictions of pilot performance. The passive seismic and the cross well tomography depend on access to wellbores or drilling new wellbores.

Also, although not specified in the budget, we have agreement with Curtin University in Australia and Rite in Japan to support our seismic monitoring with laboratory studies.

Tiltmeter Monitoring

Tiltmeter mapping technology can be used for the long-term monitoring of subsidence or dilation caused by production or injection. The fractures (i.e. cleats) in coalbed methane reservoirs provide the permeability which allows injection and production of CBM. They open and close in response to variations in effective stress due to injection and production and due to swelling/shrinking of the coal matrix caused by adsorption/desorption of the gaseous components. These deformations may be monitored by tilt meters providing they are sensitive enough. This technology has been successfully applied to detect out of zone fracture growth, slurry injection, water flooding and steam flooding.

Geochemical Monitoring Plan

The geochemical field monitoring is split into three parts. Shallow, deep and in-situ based on the depth of monitoring. The intention is to monitor movement of fluids and gases during injection of CO_2 in the coalbed methane reservoir, in aquifers directly above the CBM reservoir, in existing water wells and in the shallow vadose zone.

In-Situ Monitoring

Pressure monitoring is commonly used to evaluate reservoir response in the oil and gas industry. Interference tests, periodic fall-off testing of injection well and periodic shut-in testing of production wells are recommended to evaluate the changing permeability of the reservoir during piloting. N_2 has been chosen as a tracer as it has a higher mobility than CO_2 and will break through much earlier at the production wells in any multi-well pilot. The behaviour of this tracer will be used to evaluate and tune the reservoir models, and to make improvements to the CO_2 injection strategy to optimize pilot assessment. Analyses of produced fluids will be used to detect breakthrough of the injected gases.

Subsurface Aquifer Monitoring

In the event that injected CO_2 escapes through the upper seal of the coalbed methane reservoir and seeps into an aquifer, it is recommended that an observation well be placed in an aquifer adjacent to the CBM reservoir and monitored for pressure and fluid composition

Water-well Sampling and Monitoring

Well-water quality is a prime concern of stakeholders involved in CBM project areas of Alberta. The AGS recently completed a study investigating quality of water associated with coal beds and interbedded coal-sand aquifers across the Alberta Plains (AGS Earth Sciences Report ESR 2003-04, shallow coal-aquifer water chemistry in Alberta).

Recognized within the study was the need for high quality data that goes beyond the minimum required sampling for drilling applications and subsequent aquifer and water-well monitoring. Detailed chemistry is needed to establish proper baseline conditions, and to monitor potential changes in aquifer chemistry during production, and to evaluate potential interactions of groundwater and injected CO_2.

Produced water chemistry will be expected to be highly variable throughout the basin and hence needs to be monitored frequently. A detailed examination of water chemistry is required to assess possible disposal and alternate uses of produced waters.

AGS can be instrumental in ensuring a well-designed water sampling and monitoring program. Sample sites are pre-screened to ensure well bore conditions are suitable for the sampling study. Strict sampling protocols are ensured throughout the process to ensure minimize contamination and uphold quality control. AGS works with a variety of labs for analysis, each of which has met our quality control specifications for water analysis. The University of Calgary has analytical capabilities to conduct chemical and isotopic analyses on fluids and gases and is interested in performing such analyses on produced fluids and water obtained from deep and shallow aquifers.

Methodology

Water well site selection and screening – AGS has in-house water well databases and GIS screening capabilities, as well as geology computer models that allow selection of wells in specific lithologies, coal zones or formations.

Public contact experience – AGS has experience and a good reputation with landholders, for establishing contact with and gaining access to domestic water wells.

Sampling – Both the University of Calgary and AGS have mobile water-sampling laboratories and all the required peripheral equipment –they can move on-site and do a proper sampling program with minimal disturbance to landowners, and to wellhead sites.

Proposed sampling –

- Water wells/shallow aquifers: Based on experience, although many water wells may be available, many do not meet sampling requirements (poor screen intervals, location of pump in well, not in proper Formation or lithology, filtration, etc). Detailed well screening will be required to select suitable candidates for sampling. We suggest approximately 25 sampling sites. Sites should be sampled 2 to 4 times a year.

- Deep aquifers: Dependent on accessibility, likely one monitoring well with monthly sampling to monitor contamination with CBM fluids.

- Produced fluids and gases: sample CBM wells in vicinity of pilot monthly and sample two pilot wells weekly with continuous monitoring of gas and water for breakthrough.

Chemical and isotopic analyses – The University of Calgary has analytical capabilities to determine the required chemical and isotopic parameters of both gases and water.

Soil Gas Monitoring

In the event that the injected CO_2 finds a short circuit to the surface, soil gas monitoring and monitoring of water wells can be used to detect build up of CO_2 in the near surface. Care must be taken to distinguish the source of the CO_2 build up as organic activity in the surface soils can mask any CO_2 leakage from depth. The University of Calgary can conduct the soil gas monitoring. The group has not only the analytical capabilities to conduct the necessary chemical and isotopic analyses, but also has experience with soil gas measurements in agricultural settings in Alberta. This experience will be valuable in delineating natural and potential (yet unlikely) injection-derived contributions to the soil gas pool. Samples would be taken monthly.

Geological Baseline Plan

Geological Evaluation: Geology of strata overlying and interbedded with the coal seams of the Ardley Coal Zone, ECBM site.

AGS will create cross sections and maps from a 3-D model of the distribution of coal and associated lithologies for the Ardley Coal Zone in the study area. There are approximately 100 wells in the project area. These wells will be picked and modeled to highlight the geological features of interest.

Table B1: Budget for monitoring program

Monitoring Activity	Amount
GEOPHYSICAL MONITORING	
Seismic	
Baseline 3C-3D Seismic survey	$100,000
Baseline Vertical seismic profile (VSP)	$50,000
Total =	$150,000
Timelapse 4D Seismic survey #1	
After 6 months of CO_2 Injection	$100,000
Timelapse VSP survey #1	$50,000
Total =	$150,000
Timelapse 4D Seimic survey #2	
After CO_2 break through	$100,000
Timelapse VSP survey#2	$50,000
Total =	$150,000
Passive Seismic including drilling	$50,000
dedicated well (well = $200,000)	$200,000
Total=	$250,000

Cross Well Tomography including	$75,000
Drilling additional well (well = $200k)	$200,000
Total=	$275,000
Tiltmeters	
Issue is whether to purchase tiltmeters	
Or hire Pinnacle to do the survey	$100,000
Total =	$100,000
GEOCHEMICAL MONITORING*	
In-Situ Monitoring	
Continuous gas composition measurements	$25,000
Produced water and gases	$100,000
Well testing	$25,000
N_2 tracer	$50,000
Total =	$200,000
Subsurface Aquifer Monitoring	
Surface readout for pressure plus	$100,000
Water samples plus drilling well, well = 200k	$200,000
Total =	$300,000
Water-well Monitoring	
Baseline	
25 wells sampled	$14,000
25 water & gas analyses	$32,500
Sixth month survey:	
25 wells sampled	$14,000
25 water & gas analyses	$32,500
Twelve month survey:	
25 wells sampled	$14,000
25 water & gas analyses	$32,500
Total=	$136,500
Soil Gas Monitoring	
Install 15 shallow wells plus sample/analysis	$100,000
Total =	$100,000
Baseline Geology	
Geology of coal, seals and aquifers	$8,000
Funding Total =	**$1,819,500**

* Note: Mineralogical analyses are not part of this budget.

Summary

This appendix is a work in progress and its purpose is to develop a monitoring plan that is comprehensive. It is intended that during development of the plan, the monitoring team is also being developed and appropriate linkages established. This plan would also serve as a template for other projects and is owned by its proponents. The development of this technology is best carried out by research Organizations and Universities, and its development and deployment should be done in the public eye. The confidentiality of the data from the pilot can be protected by normalizing the data when it released publicly in monitoring technology publications such as theses, reports and articles.

APPENDIX C - THE NEED FOR AND THE FORM OF AN INTEGRATED CO_2 CAPTURE AND GEOLOGICAL STORAGE ECONOMIC MODEL

By Bill Gunter, Alberta Research Council Inc.

The world is moving towards a "carbon-constrained" economy that offers opportunities for new technologies that industries can capitalize on and grow. CO_2 Capture and Geological Storage (CCGS) can be one of the important Canadian solutions to address global greenhouse gas emission issues. CCGS allows high rates of CO_2 uptake, allows continued use of fossil fuels and provides the time necessary for the transition to fossil energy. The Western Canadian Sedimentary basin has a large capacity for CO_2 Storage and a wide range of CO_2 sources for capture. Storage options include CO_2-enhanced oil recovery, CO_2-enhanced coalbed methane recovery, CO_2 storage in saline aquifers and CO_2 storage in depleted oil and gas reservoirs.

An evaluative numerical tool is needed to assess storage options both from a business perspective (e.g. project value, CO_2 credits) and from a policy perspective (e.g. emission reductions, taxes and royalities). The tool must be based on sound engineering design, embody fiscal and royalty considerations, generate credible results, include a wide range of options, and be useable by both industry and governments. Such a model is not currently available. However, components of such a model exist. SNC Lavalin (SLI) has a CO_2 a Capture and Transport model, the Alberta Research Council (ARC) has an injection/production economics model with/without CO_2 storage. Merak's Petroleum Economic Evaluation Program (PEEP) handles financials and royalties for oil and gas properties, Analysis Works also has a model which does fiscal regimes evaluation for fixed Capture and Storage scenarios, and Energy Navigator's (ENI) model does reservoir forecasting and economic analysis (decline analysis, financial, taxes and royalties). An integration of the ARC injection model, SLI capture model and ENI forecasting and economic models would allow the economics of capture and storage projects to be evaluated. New modules that would need to be added are fluid property data and geological information, type injection/production curves for enhanced recovery of oil and CBM and type injection curves for aquifer storage and storage in depleted oil and gas reservoirs. Integration of these three models and attachment of the new modules would form a simple to use, powerful CO_2 capture and geological storage economic model, Figure C1.

The SLI capture model evaluates CO_2 capture and separation from power plant flue gas and other similar sources taking into account flue gas desulphurization, CO_2 compression, pipelining, injection surface facilities, CBM gas recovery and treatment, economic analysis and net CO_2 calculations. The model is modular and new processes can be added easily. It is based on conceptual engineering design, vendor quotes, process simulations (e.g. Mitsubishi process data for CO_2 recovery plant). The initial design basis was a 400 MW coal-fired power plant. It automatically scales based on desired flue gas quantity. It has been used and refined over 3 years for evaluation of power plants, cement kilns, and pulp mill waste. The ARC injection model is capable of being used for pilot project/commercial development, and includes process flow design, and ECBM analysis based on injection/production curves calculated in a reservoir simulator. It is MS Excel-based and able to be integrated easily with other models. The ENI forecasting and economic model can import from a wide range of data sources including MS Excel, easily run price and cost sensitivity analysis, perform before and after-tax analysis for all fiscal regimes in Canada, 95% of the US and selected international countries. It can export information to a variety of sources using an open data concept, and can trouble shoot wells using a powerfully sorting and reporting capability. It is used in engineering studies for well review and optimization by evaluating CO_2 injection analogues throughout the world, tracking well performance with comparison to analogues, and performing vintage type well analysis. It can forecast production performance using state of the art decline tools, determine monthly forecasts and reserves, split production by working interest, and automatically transfer data to the economic engine. Risk is evaluated by using chance of success and chance of occurrence techniques, running detailed sensitivity analysis on individual cases or the entire project using the powerful "Scenario Manager". "Price editor" automatically adjusts all royalty prices when you change benchmark prices.

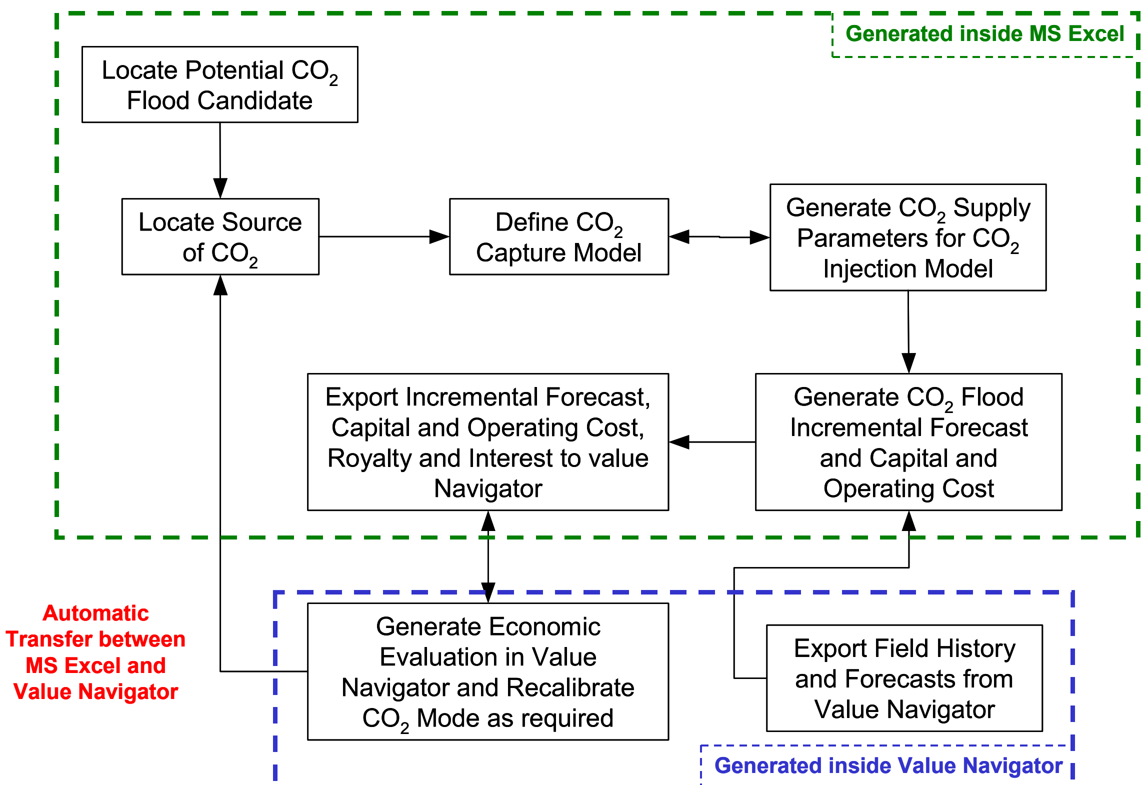

Figure C1: Example of Capture and Storage Economic Model for CO_2 EOR Scheme

Both the CO_2 capture and injection models can be easily combined (as illustrated in Figure C1) since they are MS Excel-based. The forecasting and economic model has the ability to import all capital costs, production forecasts, scheduling information and royalty parameters directly from MS Excel or for export to MS Excel. The forecasting and economics model will quickly generate before and after tax economic indicators and run sensitivity analysis. The integrated model must be able to handle the four distinct businesses – CO_2 capture, CO_2 transport, injection/energy production and CO_2 storage/credits. It must 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 greenhouse gas accounting to generate credits, conventional injection/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, a friendly user interface with tables and graphics outputs. The modular construction will allow simple modifications to be made to expand to include additional CO_2 capture technologies and storage options. CANiSTORE needs to develop or have access to such an economic model in order to make it investments wisely..

APPENDIX D - A SYSTEM TO FACILTATE CAPTURE AND STORAGETRANSACTIONS: THE CO_2 HUB

By Michelle Heath, The CO2 Hub Inc.

The CO_2 hub is a unique, multi-level online auction website designed to foster the development of a sustainable carbon dioxide (CO_2) market.

The CO_2 hub provides - for the first time - the seamless auction logistics necessary to bring together buyers and sellers of CO_2, as well as providers of auxiliary services such as purification and transportation. This format provides the motivation to encourage an energy sector market activity which establishes the availability of long-term supplies of CO_2 at economically viable price levels for the purpose of enhancing petroleum production and sequestering CO_2 emissions in geological media.

For companies who produce CO_2 and are looking for market opportunities, and for companies who are in search of CO_2 for enhanced recovery projects or other industrial uses, *the CO_2 hub* Market Floor introduces new and significant benefits, including:

- Suppliers can anonymously post CO_2 for sale, set their own reference price and receive bids from potential buyers;
- Buyers can anonymously post requests for CO_2, set their own (delivered) reference price and receive bids from potential suppliers;
- If the product specifications differ between those requested and offered, auxiliary purification (as well as transportation) auctions will automatically be spawned;
- This auction platform encourages the inherent benefits of timeliness, choice and overall best economics; and
- Volumes of CO_2 bought and sold are monitored, for the purpose of supporting future emissions credits.

Buyers and sellers of CO_2 also have the opportunity to post direct requests for services such as purification, compression, storage and transportation. For these auxiliary service providers, *the CO_2 hub* provides:

- New business development opportunities, through the anonymous monitoring of, and responding to auction events where auxiliary services are critical in delivering the suppliers CO_2 to the buyer, as requested.

All registered Users, as well as visitors to *the CO_2 hub*, may also reference the AnalystsHub, a section of links to articles and websites featuring information on CO_2, its utilization in enhanced petroleum recovery and related energy and environmental issues.

The CO_2 hub website is found at www.theco2hub.com .

As the Technical Plan for CANiSTORE enunciates, CANiSTORE can be a focal point for the research, technology, education and promotion of CO_2 Management activities to meet several strategic objectives, including:

- Providing a sustainable future for oil and gas production through enhanced petroleum recovery initiatives utilizing CO_2;
- Meeting CO_2 emission targets through geological sequestration; and
- Obviating future requirements to purchase carbon credits internationally.

CANiSTORE has addressed virtually every major aspect of the project process, with the exception, perhaps, of the *facilitation infrastructure*. In order to take the Technical Plan from idea, to pilot, to commercialization, there is a significant investment necessary in such a *facilitation infrastructure*, but it is the component of the project process that fosters strategic partnerships and infrastructure, identifies sustainable CO_2 supplies and markets (geologic reservoirs) and advances and promotes Canadian technologies internationally. The *facilitation infrastructure* could also provide measurable and auditable results of the pilot projects and ultimately enable the seamless transition to commercialization.

'the CO_2 hub' would serve well as that *facilitation infrastructure*, helping to identify potential projects and partners, monitor the CO_2 supplies delivered to the pilots and promote the development of the necessary service infrastructure required for project commercialization possible synergies and funding issues.

Just some of the ways that *the CO_2 hub* might fulfill this important process are as follows:

1. Identify Partners for the Pilots:

    a. As *the CO_2 hub* is inherently designed to foster partnerships across the entire CO_2 supply chain (buyers, suppliers, and auxiliary service providers), it can provide a mechanism for potential pilot participants to express their interest through *the CO2 hub* portal in order to streamline election and selection of interested parties.

2. Ensure Sustainability

    a. With commercialization being the ultimate objective of the pilots (and costs are always a concern), it's important from the beginning that you deliver best economics. '*the CO_2 hub'* was designed to deliver timeliness, choice and best economics … the best price to the CO_2 suppliers and the least cost to the users. The way this is achieved is through *the CO_2 hub's* unique Market Floor approach where suppliers can anonymously post supplies and receive bids from potential buyers or, vice versa, buyers can anonymously post requests for CO_2 and receive bids from potential suppliers. If the product specifications differ between those requested and offered, auxiliary purification auctions will automatically be spawned, followed by transportation auctions so that prior to placing a bid, the buyer understands the total delivered cost of CO_2 to the field.

    b. The following questions relating to the sustainability of enhanced petroleum projects and geological sequestration can be determined through the *facilitation infrastructure* inherent on *the CO_2 hub* – are there sustainable supplies of CO_2, available transportation, the necessary stripping and purification infrastructure etc., and all at affordable costs? Is there an Alberta, Canadian or international emissions trading industry opportunity? Where is the geological media for storage, how much is available, where has it been utilized, how much has been stored, by who? And many other questions that can only be addressed through an auditable central repository of transactions and processes.

3. Aid in the commercialization of the projects.

    a. *'the CO_2 hub'* could potentially provide participation with no facilitation costs to the participants of the pilots so that CANiSTORE benefits from the widest possible level of participation by all of the supply chain players. This supports a more opportune scenario for viable market conditions.

    b. This market-based approach allows for a seamless transition from the pilot stage to commercialization.

4. Monitor the CO_2 delivered to the pilots.

    a. No pilot would be successful without a thorough quantification and audit of the experience and results. As *the CO_2 hub* provides a central repository for the transactional aspects of the pilot, the CANISTORE could gather detailed information in regard to the success criteria it defines, for example, the volume of CO_2 moving to each of the buyers involved.

5. Promote Technology Transfer and International Investment Opportunities

    a. Although CANiSTORE is originally targeted at the western Canadian geography, it will expand to consider Canadian wide experience, and ultimately international. '*the CO_2 hub'* is generating tremendous interest both from an educational and subscription basis. CANiSTORE could benefit from this international trading and educational infrastructure experience to increase their visibility and success.

6. Education among stakeholders

    a. More specifically, the Analysts' Hub feature of *the CO_2 hub* (http://www.theco2hub.com/analystshub.aspx) is a repository of large volumes of information pertinent to CO_2 market analysis and related issues.

APPENDIX E - A FIELD CENTRE TO INTEGRATE CAPTURE AND STORAGE: THE HEARTLAND PROJECT

By Rick Chalaturnyk, University of Alberta and Bill Gunter, Alberta Research Council

It is proposed that for initial pilots, CANiSTORE will identify and establish a pilot project location near an industrial complex emitting large quantities of CO_2 overlying a range of geological media suitable for CO_2 storage so that minimal pipelining of CO_2 is required. Requirements for the location are: it is a large industrial complex which has several types of CO_2 waste streams, it overlies a range of geological storage reservoir types including CBM and saline aquifers, the portion of the sedimentary basin where the industrial complex is located is in a mature stage for CO_2 injection (i.e. depleted in oil and gas), easily accessible to oil and gas industry infrastructure, and to the oil and gas producers.

Over the past year of assessments, the top contenders for pilot location sites were the Edmonton/Fort Saskatchewan area or the Joffre/Red Deer area in Alberta, which are CO_2-emissions hubs. Based on a number of factors related to the practical implementation of a storage project and the availability of a variety of CO_2 sources, the Edmonton/Fort Saskatchewan area was chosen as the most suitable site and the project was entitled the Heartland Capture and Geological Storage Project (HCGS, Figure E.1).

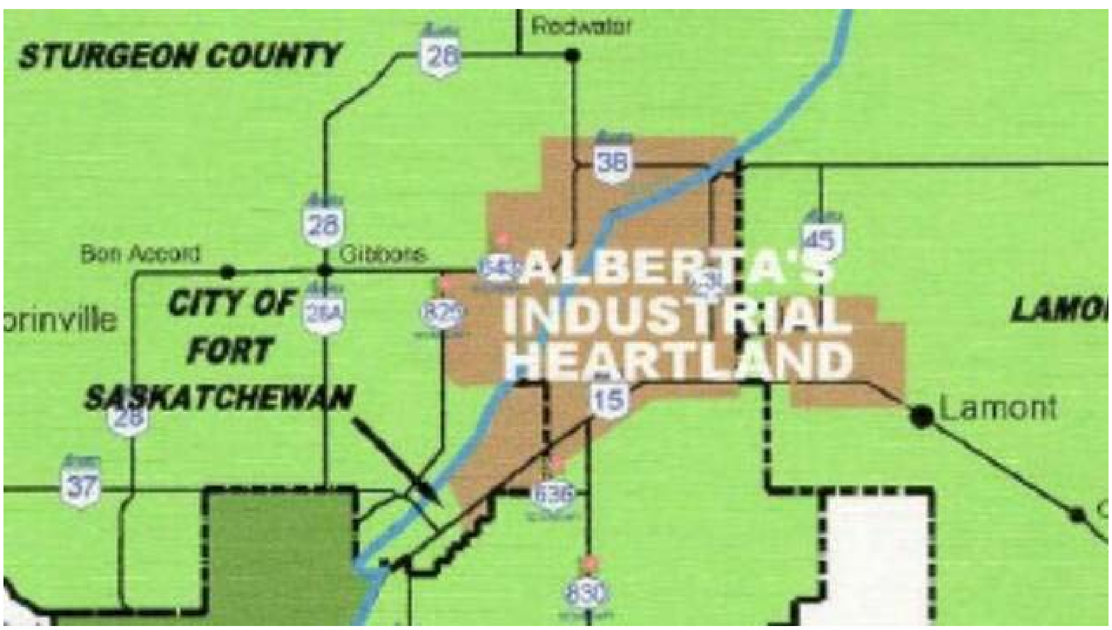

Figure E.1 General location of the industrial area NE of Fort Saskatchewan – Alberta's Industrial Heartland

Figure E.2 provides a more detailed breakdown of the areas within this industrial area and provides an aerial photograph which illustrates the fortuitous proximity of the Industrial Heartland area to the Redwater oil and gas pools.

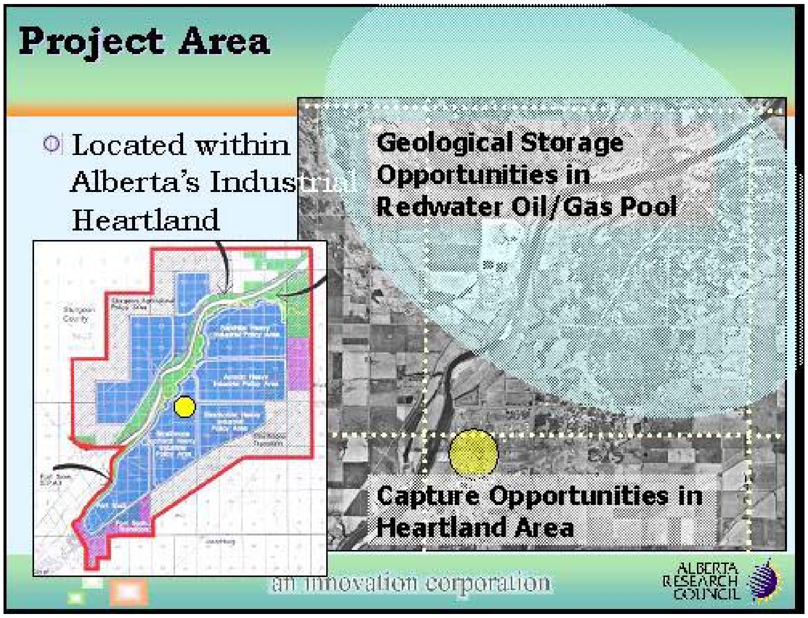

Figure E.2 Detailed plan view of industrial area and associated proximity to oil and gas pools in the Redwater area.

For the storage component of the project, the geological conditions within the Redwater oil and gas pool provide suitable, multiple horizons to target for injection. Figure E.3 illustrates that oil (albeit, highly depleted) pools, gas pools, saline aquifers and limited coalbed methane reservoirs exists in

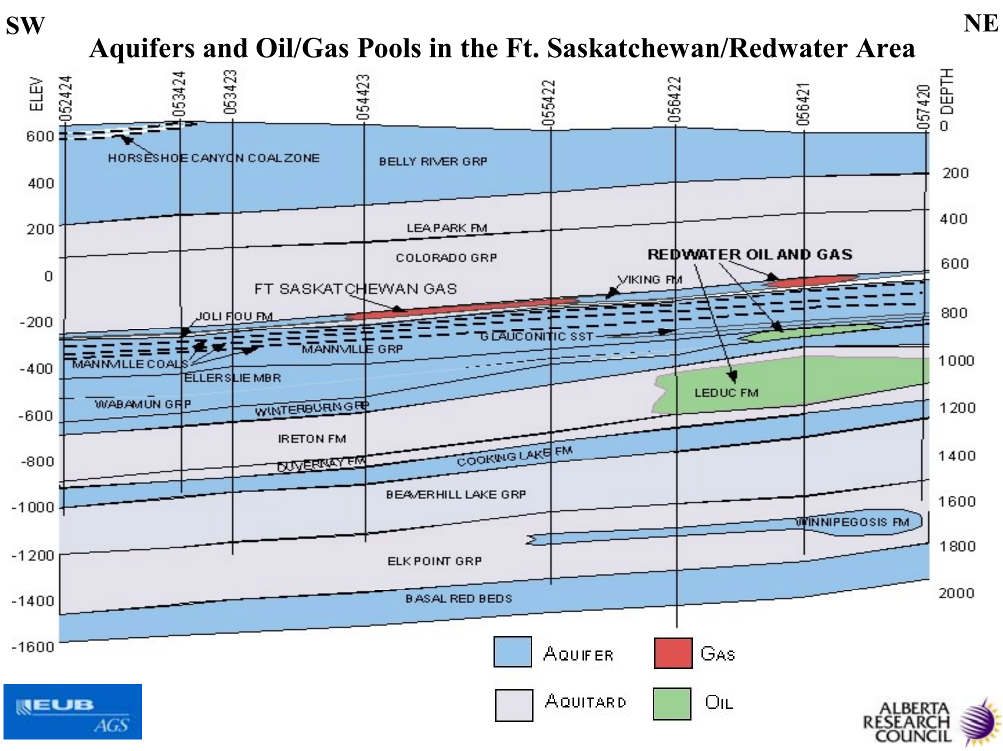

Figure E.3 Range of geological horizons possible for the project storage component close proximity to the Industrial Heartland area.

Another valuable benefit that exists within the Heartland area and the Redwater oil and gas developments is the wealth of infrastructure available to the project. Figures E.4 and E.5 illustrate the distribution of existing wells and pipelines within the project area.

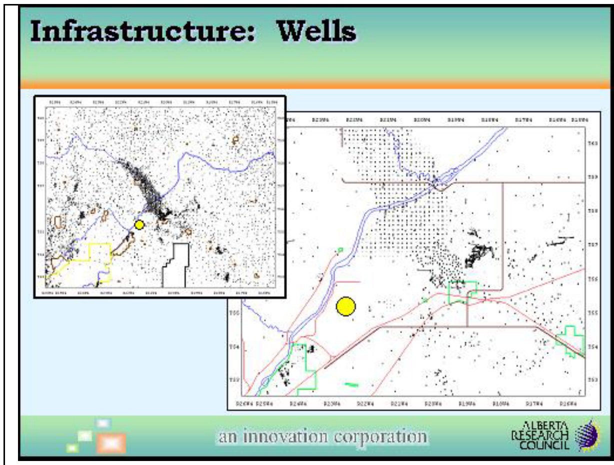

Figure E.4 Wells within project area

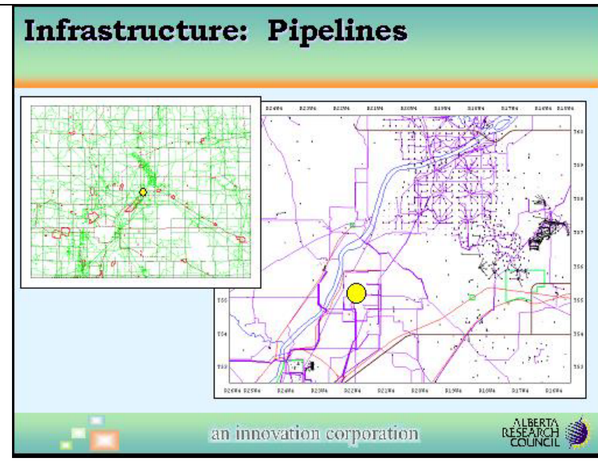

Figure E.5 Pipelines within project area

Measurement and Monitoring

The current focus for many organizations pursuing the development of a geological storage industry is measurement and monitoring of CO_2 storage. Measurement and monitoring provide the confidence that the CO_2 has been stored in an environmentally sound and safe manner and provide the accounting metrics necessary for emissions trading scenarios based on geological storage. Consequently, the context for integrated monitoring programs conducted within the HCGS project are:

- Measurement, monitoring and verification;
- Performance measures during the injection operation;
- Drivers for the technology development programs; and
- Integration with life cycle and risk assessment programs.

The philosophy for the measurement and monitoring program is based on three phases or steps in the monitoring strategy:

- **Operational Monitoring**, which is primarily governed by existing regulations and the classification of the particular well type;
- **Verification Monitoring**, which is primarily aimed at assessing spatial and temporal distribution of CO_2 and would involve a staged implementation based on the assessed risk level for a particular storage project; and

- **Environmental Monitoring**, which is last resort monitoring primarily aimed at monitoring when verification monitoring establishes deviation from expected behavior

The environmental monitoring phase is of particular importance as it represents an expansion of verification monitoring when migration or leakage of CO_2 is detected beyond the intended injection horizon.. The HCGS Project will allow focused, targeted technologies to be employed in a manner which helps define when the transition from verification to environmental monitoring should take place. Figure E6 provides a schematic representation of the monitoring levels to be employed within the HCGS Project.

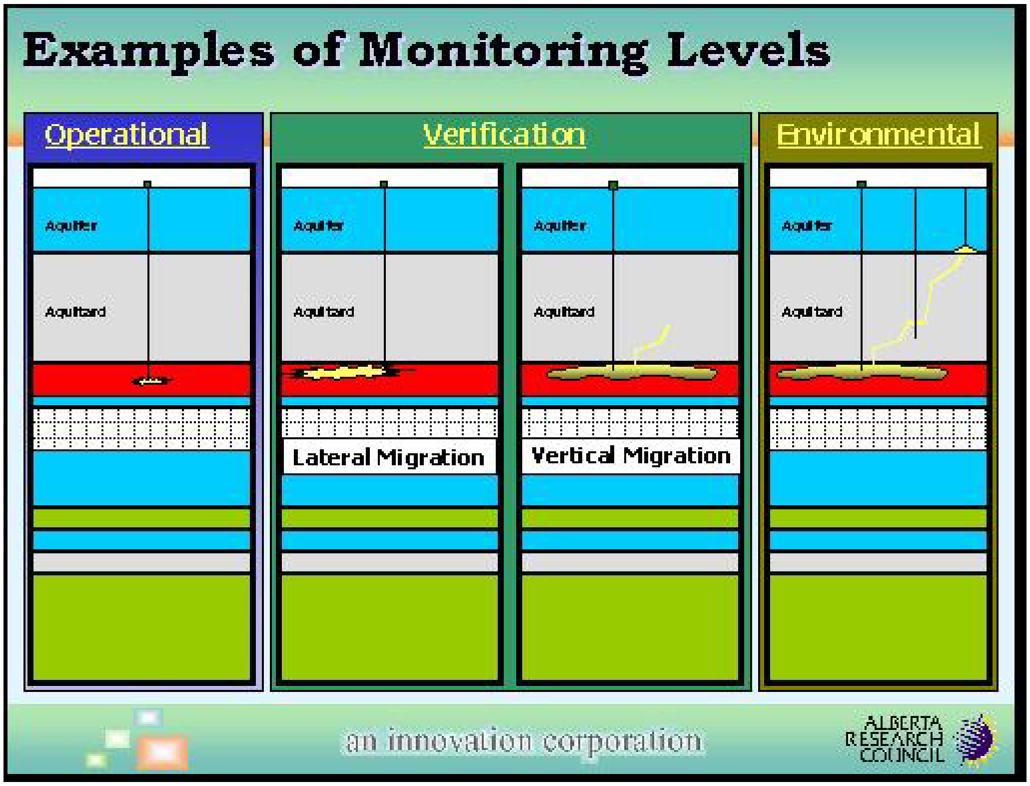

Figure E.6 Schematic of the evolution of monitoring programs from observational to verification to environmental

To implement the phased monitoring approach within the HCGS Project will require careful attention to injection/production well placement (depth, location, spacing, etc.) in order to minimize capital and operating cost and maximize the engineering and process information obtained during the project. An advantage of the suggested site is that it may be possible to utilize advances in current drilling/completion technologies to achieve these competing objectives. Figure E.7 provides examples of well geometries that may be possible within the HCGS Project. As illustrated, the ability to access several injection horizons from a single wellbore provides a compact solution to injection of CO_2 into multiple horizons and the installation of monitoring instrumentation.

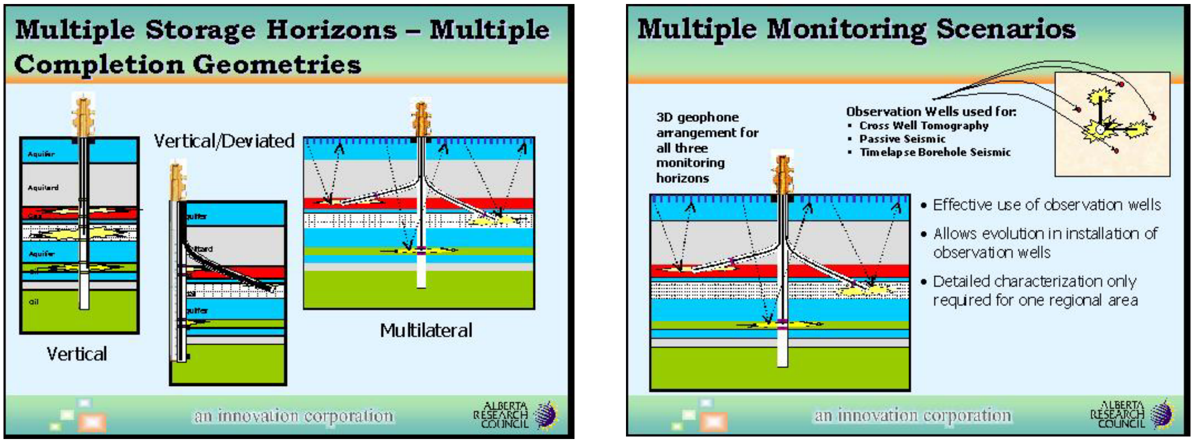

Figure E.7 Options for well completions and monitoring scenarios

The HCGS Project is proposed to be an integral component of CANiSTORE and as such, will be supported by the entire science and technology programs. This is a very significant advantage for the HCGS Project. CANiSTORE will have the technical capability to manage and assist in the project design, including initial regulatory issues, outreach or public consultation and wells and surface facilities design. The entire process of AEUB application for project approval, detailed design and costing, tendering, development of strategic alliances for professional services, construction and commissioning and ultimately, operation will all be executed by or assisted by the technical team within CANiSTORE. In particular, the integration of the science and technology programs within the HCGS Project will ensure that research and development programs evolve as knowledge gaps are identified throughout the Project.

In this regard, preliminary budgets developed for CANiSTORE (Appendix H) include separate budget items for the HCGS Project. Appendix H highlights estimated budgets for HCGS Project Design, Construction, Monitoring Programs, and Operation. Included in the budgets are the estimated costs for transition from the pilot scale of the HCGS Project to a commercial scale project for geological storage of CO_2. The science and technology programs (except for MMV) are not included in the HCGS budgets but are separate items.

Benefits of the HCGS Project

Within the context of CANiSTORE and even as a stand-along project, the Heartland Capture and Geological Storage Project has the potential to provide substantive operational and technical knowledge to assist in the evolution of a geological storage industry in Canada. The following list provides some of the major benefits:

Ideally structured to take advantage of CO_2 capture and storage incentives offered by Provincial and Federal Governments;

- Allows companies to "commit to action and engagement with government, society and other businesses to contribute to international, national and regional solutions";

- Provide life-cycle assessment scenario for establishing realistic GHG targets for industries within Heartland region;

- Capture and Storage components of Project can be integrated with CO_2 market trading entities such that market-based mechanisms for CO_2 emissions and management can be assessed;
- An industrial association (the Heartland Association) that has actively engaged its stakeholders in seeking solutions to industrial development and has begun educating its membership on the concept of Geological Storage;
- Integration with CO_2 capture allows full life cycle of sequestration to be studied;
- Located close to CO_2 sources (as well as other waste gas streams) so long distance pipelines not required;
- Multiple storage scenarios piloted with minimum of infrastructure (fewer wellbores);
- Proximity to active geological storage research entities (ARC, UofA, UofC, etc.) permits effective capacity building and training through involvement with HCGS ;
- Design of pilot will allow assessment of “future” monitoring technologies (i.e. micro-sensors, etc.);
- Integrated monitoring programs inform balanced policy development concerning measurement, monitoring and verification (through over-instrumented pilots).

APPENDIX F - FRAMEWORK FOR INTERNATIONAL PROJECT COLLABORATION AND SCIENTIFIC EXCHANGE: PART A – AUSTRALIAN MISSION

Australian Trip Report December 8 to 18, 2003

By William D. Gunter, Alberta Research Council, Canada

With Australia Day & IPCC reports by Malcolm Wilson, University of Regina

Introduction

The timing of the trip was dictated by the meeting of IPCC Special Report (on CO_2 Capture and Geological Storage feasibility) Team in Canberra from Dec. 16 to 18 which included 5 Canadians. Trip itinerary was arranged by Andy Rigg and Peter Cook of the Australian CO_2 CRC to meet with industy, universities, state government, national government and CSIRO who were participating in the CO_2 Cooperative Research Centre (CO_2 CRC). The CO_2 CRC is a 7 year program funded by the Australian government with a grant of \$21 million which has been leveraged through contributions from other members of the CRC to \$120 million. The purpose of the CO_2 CRC is to conduct research in and develop technology for accelerating the commercialization of CO_2 Capture and Geological Storage (CCGS) in Australia as an aid in reducing GHG emissions. My intent was to establish contacts and identify opportunities for Canadian technology transfer to Australian entities and to learn of Australian programs and technologies which could be applied in Canada and identify opportunities for working through the CO_2 CRC towards commercial opportunities. The areas of expertise needed for the trip were CO_2 Capture, Geological Storage and Policy.

The following Canadians were invited Kelly Thambimuthu (NRCan), Malcolm Wilson (University of Regina), Bill Reynen (Environment Canada), David Keith (Carnegie Mellon University and University of Calgary), Bill Gunter (Alberta Research Council = ARC), Ian Potter (Alberta Research Council), Eddy Isaacs (Alberta Energy Research Institute) and Bob Mitchell (Alberta Environment). Although all of these people expressed interest, the only person able to go on the trip was Bill Gunter whose expertise was in Geological Storage. However, David Keith and Stefan Bachu were able to participate for short periods in Canberra where the IPCC meeting was being held.

The centers for CCGS activity in Australia are Perth, Adelaide, Melbourne, Canberra, Sydney and Brisbane. Due to the 6 days available before the IPCC meeting in Canberra, visits were only made by Bill Gunter to Perth, Melbourne and Canberra, allowing two days for each center. Andy Rigg and Barry Hooper of the CRC accompanied me on my visit to Melbourne.

PERTH, Western Australia visit (December 8 & 9)

(1) ChevronTexaco

Met with the ChevronTexaco Australia Pty Ltd team (approx. 10 people) responsible for Gorgon Subsurface Development and gave them a talk on The Approach to and Activities in Geological Storage in Canada. My host was Rob Root, a geoscientist on the team. Jason McKenna, a geophysist and Matthew Fleet, a reservoir engineer were particularly interested in the Canadian work. The Gorgon project will produce natural gas offshore in Western Australia which has a high CO_2 content; it will separate the CO_2, liquify the natural gas, and pipeline the CO_2 to Barrow Island where it will be injected into geological media at the approximate rate of 5Mt/yr. The ChevronTexaco team is choosing the subsurface aquifer site for storage.

The proposed development will include around 20-30 offshore sub-sea development wells, a pipeline from offshore to Barrow Island, a gas processing facility, a 5 Mt/yr LNG train in the first stage (projected at around 2008), and a second 5 Mt/yr train in the second stage (projected at around 2010). The development will ultimately also include a domestic gas pipeline from Barrow Island to mainland Australia. The project is currently negotiating sales agreements for LNG to underpin the project and is about to commence the front-end engineering design works (with most of the concept selection work already complete).

It is proposed that up to 5 Mt/yr of carbon dioxide will be sequestered in a saline (aquifer) formation below Barrow Island. The initial injection rate is estimated to be between 2.6 and 4.2 Mt/yr of carbon dioxide, depending on the initial LNG plant capacity. The total volume proposed to be injected over 30+ years is about 150 million tonnes of carbon dioxide. The injected gas composition will be primarily carbon dioxide, but may also include small quantities of hydrocarbons, water, hydrogen sulphide and nitrogen.

Legislation is currently before the Western Australian State parliament to enable access to Barrow Island for the Gorgon Development. This enabling legislation also includes provisions for modification of existing petroleum and pipeline regulations to provide for the geological storage of carbon dioxide as part of the project. The early approval of this legislation will provide the Gorgon venturers with increased certainty to move forward with the project within a relatively short timeframe (i.e. 5 years to obtain all necessary approvals, complete the detailed design and construct the facility).

(2) Department of Industry and Resources, Western Australia

Met with Bill Tinapple (Director of the Petroleum Division) and Colin Williams (petroleum Engineer in the Resources Branch of the Petroleum Division). They are following the Gorgon project quite closely and are very interested in monitoring technologies which may be applied. They indicated that they are partly relying on Curtain University to develop these technologies. There are offshore issues to ownership between the State and the Federal Government. The Gorgon project falls under both State and Commonwealth jurisdiction. The natural gas is produced from Commonwealth waters and the CO_2 is being injected into geological formations that come under State government jurisdiction.

(3) Woodside Energy

Met with their subsidiary, Metasource Pty Ltd. My host was Peter McNally (Greenhouse & Climate Change Coordinator) and I met with a group from Metasource consisting of Brian Dadd (Technology – Investment Manager), Steve Waller (Greenhouse Opportunity Manager), Garry Triglavcanin (Senior Investment Advisor), Tim Hanlin (Commercial – Investment Manager), and Mark Weinman (Manager) in their "War Room". We had a good discussion about the business opportunities in geological storage.

(4) CSIRO Petroleum

Gave a talk on "The Approach to and Activities in Geological Storage in Canada" to CSIRO and Curtain University.

Met with Greg Thill (General Manager for Business Development) to discuss extended visits of scientists between CSIRO and ARC programs in CCGS. As the CO_2-CRC is directing this program in Australia, we agreed that any transfer of a CSIRO employee or an ARC employee to the other should also involve the CRC. The CRC could fund any Canadian visitor to Australia working on Australian CCGS projects at CSIRO or another Australian entity. Conversely, any Australian visitor to Canada to work on a Canadian CCGS project should be approved by the CRC as well as by his parent entity, and would be funded by ARC or another Canadian entity. Scientists from CSIRO (CBM expertise) and ARC (geochemical expertise) were identified for possible visits, and we agreed to work on implementing these.

Met with Claus Otto (Group Leader of Geofluid Dynamics) and Jim Underschultz (Petroleum Hydrogeologist in the Geofluid Dynamics Group, CSIRO Petroleum) who moved from Alberta over 5 years ago to be employed by CSIRO. Their focus is on basin hydrodynamics integrating the fluid inclusions, petrophysics, hydrogeology, geomechanics and structural geology of the sedimentary basins in Australia to characterize sites for storage of CO_2. They were interested in Albertan projects that were injecting CO_2 and in monitoring. They felt that they could use geochemical expertise from ARC on their projects as they could provide geochemical datasets which need to be modelled/interpreted in assessing the geological storage sites. They are considering six sites across Australia.

Met with Kevin Dodds (Research Manager for Geophysics) and his group to discuss long term monitoring of geological storage sites. They are doing some interesting laboratory petrophysical measurements in partnership with Curtain University. They have developed technologies to make scaled models of portions of Sedimentary Basins using packed sand and calcite cement or bacterial waste cement where they control the permeability by sorting and grain size.

(5) Curtin University

Met with G.F. Wier (Director of Post Graduate Studies, Dept. of Petroleum Engineering) and we discussed the program that he is developing for Curtain University in Petroleum Engineering, and the concept of dual usage pipelines for CO_2 transport.

Met with Brian Evans (Professor of Geophysics, Dept. Exploration Geophysics) and he reviewed one of his projects for use of seismic to identify sweet spots in CBM. He showed me his pressure chamber for seismic monitoring of fluid flow in scaled models (approximately a cubic meter in size). I was very impressed by this piece of research equipment. Brian would like to partner with Canada and Japan in designing experiments for applying to field projects, and has sent me a proposal on this. Don Lawton (Professor of Geophysics at the University of Calgary) spent part of his sabbatical last year at Curtain University and was similarly impressed with this piece of equipment.

Have met with Robert Amin (Professor) in the past. He is working on Capture Technologies using hydrates and cryogenics.

MELBOURNE, Victoria (December 10 & 11)

(1) BHPbillington

Met with Ian Gorman (Petroleum Engineering Manager), Lino Barro (Senior Petroleum Engineer) and Mark Jackson (Production Management Advisor). Gave a talk on "Enhanced Coalbed Methane". BHP is interested in primary CBM production and Ian Gorman frequently visits Canada. They may be interested in ECBM in the future.

Have met with Jon Coates (Representative for Energy Coal) in the past. He is based in China and we discussed the potential of cooperative projects in China as BHP interests in China are developed further.

(2) CSIRO Petroleum

Although the headquarters for CSIRO Petroleum are in Perth, there is a section based in Melbourne. Met with Lincoln Patterson (Group Leader of CO_2 Sequestration/Reservoir Characterization Group), Jonathan Ennis-King (Reservoir Simulation), Mike Wold (Low Permeability Reservoirs – recently retired), Luke Connell (Gas in Coal), Rob Jeffrey (Group Leader of Petroleum Geomechanics), Xavier Choi (Petroleum Geomechanics). Three topics were discussed: Establishment of a Global Research Initiative on Enhanced Coalbed Methane with CSIRO as one of the founding members; movement of Xavier Choi from CSIRO to ARC for one year; and movement of Ernie Perkins from ARC to the CO_2 CRC for one year. For the Global Research Initiative on Enhanced Coalbed Methane, three of the four founding members are TNO, Netherlands representing Europe; ARC representing Canada; and Tesseract Corp., representing the US. It was desirable to have Australia as the fourth founding member to represent a third continent and a fourth centre of expertise. The outcome was that CSIRO does not want to be a founding member but would consider to become a participating member. Also, CSIRO felt that movement of Xavier Choi to ARC this summer through the CRC program was not possible in consideration of the number of CSIRO projects he was leading/contributing to. However, they were prepared to consider a month's visit. CSIRO was interested in Ernie Perkins working with Ennis-King on geochemical modelling but they were not sure if the CRC would benefit more by having Ernie based in Perth, Adelaide or Canberra where other geochemical CRC activities were ongoing.

(3) Australian Power and Energy Limited (APEL)

Met with David Lea (Project Coordinator) who works for Allan Blood the CEO. APEL was formed to look at long term exploitation of the Victorian wet brown lignitic coals, a huge on land resource over 100 meters thick. They termed it the "Victorian Power & Liquids Projects" which is to develop a strategy to utilize the brown coal for electricity and conversion to liquids. Issues are drying of the coals, gasification and geological storage in depleted oil reservoirs offshore at the approximate rate of 10Mt/yr. They may use the water recovered from the lignite for cooling. Dry cooling is also being considered. They have hired Fluor to do an assessment of their plan using either the Shell or Nowell (developed in East Germany) Gasifier. The Lurgi gasifier is not appropriate as it is a low temperature gasifier which leaves behind a lot of crud as opposed to these high temperature gasifiers which breakdown everything into the elements and then recombines them. He was interested in the Canadian Clean Coal Road Mapping workshop.

APEL proposes to develop Australia's first commercial coal gasification and gas to liquids project. The plant would produce 52,600 barrels per day of diesel fuel using the Fisher Tropsch process and about 500 MW of surplus power. The plant is required to sequester about 10 Mt/yr of carbon dioxide to stay within overall emission targets agreed with the Victorian State government and included as a licence condition. The project, as initially conceived, consists of the following:

- Brown coal drying and gasification process plant producing clean synthesis gas;
- Synthesis gas based hydrogen production and purification plant;
- Fischer Tropsch fuel synthesis plant;
- Associated waste heat recovery and off gas power plant;
- Geosequestration facility; and
- Geological storage of carbon dioxide in an offshore sedimentary basin.

(4) Clean Power from Lignite CRC (= Brown Coal CRC)

Met with David Brockway (CEO), Peter Jackson (Manager Research), Malcolm McIntosh (Manager Technology Development), Sankar Bhattachchatya ((Leader of Gasification Project) This CRC has been running for 10 years evaluating the brown (low grade) coals of Victoria. David is leaving the CRC to become the head of Energy Technologies for CSIRO and Peter will become CEO. Gave a talk on the "The Approach to and Activities in Geological Storage in Canada" as this CRC is integrating "Geological Storage" into their program for recovering energy from Victorian lignites. Currently, commercial electricity generation from brown coal by combustion costs $35/megawatt hour and is sold for $25, a losing proposition.

Commercial gasification was developed around black (higher grade) coals which achieve 35% efficiency in conversion to electricity compared to brown coals 28% efficiency. However the Brown Coal CRC has been pioneering gasification of brown coal. They currently have a gasification run where they are evaluating North Dakota/Saskatchewan lignites. Even though the North Dakota coals from the US are lignites, they are more like black coals and they don't crumble compared to Victorian coals which crumble and shrink 50% when being dryed. Issues are drying of brown coal and energy use. It is to expensive to clean up the saline water recovered from the brown coal. However, once you dry brown coal it is much more reactive than black coal. It is also cheaper to mine brown coal than black coal. This is why there is also a Black Coal CRC (= Coal in Sustainable Development) in Queensland, Australia. The Brown Coal CRC is testing entrained flow and fluidized bed options for delivering the feedstock to the gasifier . For the gasifiers, they get better efficiencies with air blown since the gasifier can operate at a lower temperature. All black coal gasification technologies use oxygen to get higher temperatures because the volumes of gas that flows through the gasifier is reduced by 50%. Oxygen blown gasification is key to liquids manufacture from syngas by Fischer Tropsch. The challenge is cheap enough syngas. SasOil in South Africa has a lot of experience with Fischer Tropsch using Lurgi gasifiers. Lurgi gasifiers operate using large particle size and can't handle the small particles from the brown coal. The Brown Coal CRC has evaluated both the Shell and the Winkler (850 to 950^{o}C) high temperature gasifiers. They found the Shell gasifier specifications too tight. They are interested in the new lower temperature Transport Gasifier being developed by Halliburton.

(5) CO_2 CRC Capture Program

The CO_2 CRC headed by Peter Cook is split into two divisions along Capture and Storage lines. The CO_2 CRC evolved from the GEODISC program (which was also led by Peter Cook with Andy Rigg as second in command) which focused on Geological Storage. In the new CRC, Andy Rigg continues to manage the Geological Storage program from his office in Sydney. Barry Hooper is the newly appointed head of the Capture Program which he runs from his office in Melbourne while the administration offices for the CRC reside in Canberra headed by Peter Cook (CEO).

CANBERRA, Australian Capital Territory (Dec. 12 & 15)

(1) CO_2 CRC Administration

Met with Peter Cook (CEO), Andy Rigg (Deputy CEO & Storage Program Manager) and Barry Hooper (Capture Program Manger). The structure of the Australian Government dealing with GHGs was discussed. GHGs fall under three departments: Dept. of Industry, Tourism and Resources (ITR); Environment Australia; and Dept. of Engineering and Science Technology. Under the Dept. of Engineering and Science Technolgy falls CSIRO, Universities, CRCs and Science Agreements. Under ITR falls Oil & Gas, Coal, Geoscience Australia, the Carbon Sequestration Leadership Forum, and environmental issues pertaining to resource and industry. Environment Australia is the main government department charged with environmental matters. The Australian Greenhouse Office reports both to ITR and Environment Australia and deals with IPCC affairs.

The CO_2 CRC is divided into three entities: the CO_2CRC Management Pty Ltd which keeps track of all financial matters, the Unincorporated JV CO_2CRC, and the Innovative Carbon Technologies Pty Ltd which is the commercial arm which exploits the IP developed under the Unincorporated JV CO_2CRC and offers a consultancy. Peter Cook is CEO of all three bodies. The Unincorporated JV CO_2CRC is split into four divisions: a Capture Program, a Storage Program, Communication & Liaison, and Education & Training. The Capture and the Storage Programs develop new knowledge and new technologies, and have R&D development in major commercial projects. Communication & Liaison promotes the Capture and Storage Programs in advising external clients of technology and assists in Pilot project development. Education & training is responsible for technology transfer.

Table F1 is a list of the technology and other areas being pursued in the CO_2CRC.

The CRC is participating in two international activities in the US, in the Frio aquifer CO_2 injection project and in FutureGen. The CRC is interested is moving Scientists and Engineers between ARC and

Australian Institutions (in both directions) involved in CCGS. It was agreed to draft a set of general principles for these visits which I am working on (see also section under PERTH [4] CSIRO Petroleum).

It was also agreed to work jointly on International projects in CCGS where appropriate. A discussion was held on submitting a joint APEC proposal for training/technology transfer to Asia and South America in CCGS. Because of commitments already in place by ARC to its Canadian partners, the small $ value of the project and the short deadline for submitting the proposal, it was decided that Australia and Canada would submit separate proposals but would join forces in any succeeding requests from APEC.

Table F1 CO_2CRC Programs and Projects in the Unincorporated JV CO_2CRC

Program/Project		**Program/Project Manager**	**Affiliation**
Group A	***Geological Storage Technologies for CO_2***	**Andy Rigg**	**CO_2CRC**
Program 1	**Storing CO_2**		
1.1	Technologies for Assessing Sites for CO_2 Storage	Dr. J. Bradshaw	Geoscience Australia
1.2	Understanding Subsurface Processes	Dr. L. Paterson	CSIRO
1.3	Better Monitoring & Verification Technologies	TBA	
1.4	Risk Assessment Methodologies	A Bowden	URS
1.5	Technical Basis for a Regulatory Regime	D Wright	Geoscience Australia
1.6	Communications	A Rigg	CO2CRC
1.7	Economic Modelling of CO_2 Storage Systems	G Allinson	UNSW
1.8	International Collaboration	A Rigg	CO2CRC
Program 2	**Demonstration Program**		
Program 3	**Using CO_2**		
3.1	Enhanced Gas Recovery (EGR)	Prof J Sarma	Adelaide
3.2	Enhanced Coal Bed Methane (ECBM)	TBA	
3.3	Enhanced Oil Recovery (EOR)	Prof J Sarma	Adelaide
3.4	Capture of CO_2 with Brines as Valuable Products	Dr G Sparrow	CSIRO Minerals
3.5	Metal Activated Conversion of CO_2	A/Prof M Buntine	Adelaide
3.6	Economic Evaluation	G Allinson	UNSW
Group B	***CO_2 Capture Technologies & Future Options***	**Barry Hooper**	**CO2CRC**
Program 4	**Capturing CO_2**		
4.1	Characterising Australian Emissions	R Sait	Geoscience Australia
4.2	Enhanced Solvent – Based Systems	Prof G Stevens	Melbourne
4.3	Innovative Membrane Systems	Dr S Kentish	Melbourne
4.4	Innovative Pressure Swing Adsorption Systems	Dr a Chaffee	Monash
4.5	Hydrate Formation & Cryogenic Distillation Systems	Prof R Amin	Curtin
4.6	Economic Meeting of CO_2 Capture Systems	A/Prof D Wiley	UNSW
4.7	International Collaboration in Capture Technologies	TBA	CO2CRC
Program 5	**Regional CO_2 Strategies & Future Energy Options**		
5.1	Regional Development Models to Decrease CO_2 Emissions		CO2CRC
5.2	Future Options for a Hydrogen Economy	TBA	CO2CRC
5.3	CO_2 Strategies for Emission Hubs	TBA	CO2CRC
		TBA	

(2) Department of Industry, Tourism and Resources for Australia

I was introduced to Tania Constable (General Manager of the Resources Development Branch, Resources Division) and met with John Karas (Manager Coal Industry Section, Resources Division) and Carolyn Barton (A/g Manger of Sequestration Regulation, Resources Division). In addition had lunch with Paula Matthewson (Deputy Director of the Australian [black coal] Coal Association).

They regard CCGS as an extremely important option for Australia. There is an initiative called "Coal 21" to accelerate uptake of clean coal technologies including CCGS. The government has established a gasification centre for black coal, and are meeting with Utilities. They would like to see a 16 megawatt gasifier built using a hydrogen turbine. The Coal Association is helping promote these activities.

They regard Canada as an attractive partner in moving the CCGS option forward on the Global agenda. They would like to see more meetings on this topic between Australia and Canada. They would like to advance the Australian – Canadian Climate Change Partnership. There are three upcoming meetings in Australia which they would like to see a strong Canadian representation. The first is the IEA Asia Pacific Conference on "Zero Emissions Technologies", February 16-19, 2004, near Brisbane, Australia. Kelly Thambimuthu will be participating in this meeting. This conference will be followed by a regulatory agencies meeting. The second is the World Energy Congress in Sept. but unfortunately it conflicts with IEA GHGT#7 Conference in Vancouver, Sept. 5 to 9, 2004. The third is the Carbon Sequestration Leadership Forum (CSFL) which meets in Australia in September the following week, Sept 13 to 15, 2004. Kelly Thambimuthu and Bill Reynen will be participating in this meeting.

An issue, that has arisen, is that Australia was instructed only to communicate with Canada in CSFL matters through Gil Winstanley (Director, International Energy division, NRCan), Teresa Marty (NRCan) or Monder Ben Hassine (Senior Advisor on CO_2 Capture and Storage, Energy Resources Branch, NRCan). This was brought up in relation to a Legal, Regulatory & Financial Issues Taskforce Draft Discussion Paper prepared by Australia for the Italy Policy Working Group Meeting in January, 2004. They would like to exchange information directly with the Alberta Government on these matters, but it is my understanding that they have been instructed not to.

(3) Australian Greenhouse Office for Australia

David Keith and I met with Roger Coogan (Assistant Manager Energy Supply Policy), and John Jende (Assistant Manger of the Energy Futures Team, Sustainable Energy Group). The Australian Greenhouse Office (AGO), founded in 1998, is an Executive Agency reporting directly to the Minister of the Environment and the Minister of Industry. The AGO is in charge of formulating domestic GHG policy. They have several programs for industry. The GHG Certification Program is a voluntary one where industry reports their efforts in reducing GHG emissions beyond "business as usual" actions for recognition in the future. The GHG Abatement Program is a reverse auction similar to the Canadian PERRL program which will fund up to $400 million in projects that will quantitatively reduce GHG emissions.

(4) University of Adelaide

Gave a talk on the geochemistry of several of the research projects in Canada: on Geological Storage including Weyburn, Acid Gas Injection and Methanogenesis. Met with the geochemistry team consisting of Peter Tingate (Senior Researcher), Jurgen Streit (Senior Researcher), Max Watson (researcher), Philippa Uwins (Senior Researcher, Whistler Research Pty Ltd) and Dirk Kirste (Researcher, ANU). There was positive support for Ernie Perkins, ARC coming to work for the CO_2 CRC in Australia next year. There are projects at the University of Adelaide for which he could help in the geochemical modelling side.

(5) Geoscience Australia

John Bradshaw (Principal Research Scientist for Geological Sequestration) toured Stefan Bachu and I around their offices. John has done the regional geological analysis to identify potential CO_2 storage areas across Australia.

(6) Australian National University

Dirk Kirste is preparing to look at geochemical reactions in the laboratory to compliment the petrographic studies done by University of Adelaide on natural analogues for geological storage of CO_2. He is supported by D.C. McPhail who is on the faculty of ANU. Both are Canadians and are also interested in Ernie Perkins spending time at ANU as part of the CRC. Presently ANU is not part of the CRC. This is an issue.

(7) Australia Day (Malcolm Wilson Report)

This was an afternoon of presentations on the CO_2 Capture and Storage Program in Australia put on for the IPCC delegates prior to their three day meeting in Canberra. The presentations were split into three groups: (1) the Australian Government talking about Climate Change, Energy and Technology Innovation Perspectives, (2) the Australian Industry on CO_2 Capture and Storage, and (3) the CO_2 CRC on Geosequestration Research in Australia. The level of support shown for CCGS by the Government, by Industry and by the Researchers was outstanding.

The meeting started with the Australians presenting "CO_2 Storage Down Under". This was a half day series of presentations on the activities underway in Australia. This included the goals of the CO_2 Cooperative Research Centre, the outcomes of the GEODISC program and some research work underway in Australia. The key element of the presentations was the level of support from the government for the program as well as the support from the industry in Australia. While relatively limited, the industry is showing strong support for the activity of the CRC. In particular, the coal industry is taking a keen interest in the CRC. While technically we are more advanced in Canada as a result of our focus on practical projects, the Australians have gained far more federal and industry support than we have been able to manage. This is not just federal money into projects, although the Australians have created the CO_2 CRC in an attempt to focus their efforts, it also includes a more consolidated federal support for activities. This is achieved under the federal Australian Greenhouse Office.

This was a useful opportunity to see how the CO_2 CRC is developing and to get some feel for the aspirations of the group. It also brought out a potential problem in that the CO_2 CRC and the western Canadian geological storage team, led by PTRC, are heading into potential conflict. Both groups are targeting the same activities and are looking to obtain the same international activity. In both instances, we are looking at becoming the centres of excellence in Monitoring and Verification and are looking to become involved in major storage projects. Canada has the edge in terms of experience and an international team, but not in terms of coordinated action nationally. We have suggested that Canada collaborates with the CO_2 CRC. It will also be well worth our while to develop a more coordinated approach with stronger support at the international level.

IPCC CO_2 Capture and Geological Storage Report (Dec. 16-18) by Malcolm Wilson

This was the second of the meetings of Lead Authors with the Technical Support Unit (TSU) and the co-chairs of Working Group 3. The majority of authors were present at the meeting and were able to discuss progress. In attendance from Canada were:

- Malcolm Wilson (Lead Author)
- Stefan Bachu (Lead Auhtor)
- Bill Gunter (Lead Author)
- Kelly Thambimuthu (Coordinating Lead Author)
- David Keith (Lead Author)

Four of the five Canadians present are part of the Geological Storage section. David Keith also acts as chair of one of the cross-cutting groups looking at Legal and Public Perception and has taken a role in the discussion of “permanence”. Anther cross-cutting group is on the Effect of Impurities in the CO_2 Stream which Bill Gunter is participating in. Kelly co-chairs the Capture section.

One of the US participants, Turekian, has stepped down. Bill Gunter replaced Turekian in the Geological Storage group.

IPCC Meeting

The IPCC remains a heavily bureaucratic process. The level of completion of the various sections is variable – ie there are still numerous sections missing. Based on the numerous comments, the level of comfort with certain sections of the report in also a concern. The TSU is hard line when it comes to inserting text that comes in after the fact – this may make things easier for the TSU, but constrains the effectiveness of the writers of the various sections. This problem was raised by the Norwegian delegate in the geological storage section.

The comments on the report were extensive in number. Comments were received from approximately 50% of the authors. These were split into general comments and specific comments, which are to be dealt with by the section authors. A considerable amount of time was spent during the meeting addressing the general comments and developing new general comments. It goes without saying that a number of the comments were frivolous or trivial in nature. Many of the comments do, however, need to be dealt with. It is also the case that many of the so-called general comments were very specific in nature. The designation of general versus specific was self-determined by the commentator, the TSU evidently did not review the comments before placing them in the closed website.

The major issues revolve around definitions of terms. The simple question of “how long will the CO_2 remain in the ground?” is a difficult one to answer. While the CO_2 will remain in the ground for some considerable time, if not indefinitely, release could be a problem locally. With biologic sequestration, the release of CO_2 is well understood and the time for storage is short. With oceans, the mechanisms for CO_2 circulation are relatively well understood. With geologic storage, however, the storage will be site dependent. Well-engineered sites will have relatively little, if any, chance for leakage to surface. The most likely avenue for leakage is along the wellbore, this is also the location most easily remediated using currently well-understood techniques. Trying to define the storage in a realistic way is challenging – David Keith has taken a leadership role in this area.

Other terms also presented some problems. Included here is the leakage, migration, seepage set of terms. It was agreed that migration means controlled movement (ie movement within the injection zone or into a zone where movement is acceptable), leakage means uncontrolled movement out of the storage container, generally towards surface, and seepage is the movement of CO_2 from the geosphere into the atmosphere. Terms such as saline aquifer versus saline formation, caprock versus seal etc were discussed. The finally acceptable terms will be clearly defined in a glossary, with a team from geological storage set up to create an early start for this chapter of which Bill Gunter is a member.

It was decided to introduce 6 Case Histories into this chapter to make the point that Geological Storage is already being practised around the world for other reasons.

The sites chosen - the type of storage (and the authors responsible) were Sleipner, Norway – Aquifer storage (Tore Torp), Weyburn, Saskatchewan – EOR storage (Malcolm Wilson), San Juan Basin, New Mexico – ECBM storage (Bill Gunter), Western Canada – Acid gas injection (Stefan Bachu), Rangely, Colorado – EOR storage (Bill Senior) and Berlin, Germany – Natural gas storage (Wolfgang Heidug). Two of the sites are in Canada.

The co-chairs and TSU will be recommending a timing change to the preparation of the Special Report. This will result in the finalisation and release of the report in December 2005 instead of May 2005. While this has to be approved, the TSU seem confident that they will be able to convince the IPCC plenary. The next meeting has been delayed until August, 2004 in Salvador, Brazil and a new meeting scheduled for May, 2005 in Spain. The timing for 2004 is not good in that it precedes the GHGT 7 conference by only a few weeks. A number of delegates requested that the Brazilian meeting be moved to the following time slot and that the August meeting be scheduled with GHGT 7. The co-chairs rejected this compromise based on the need to move meetings to other countries and to avoid having one country host two meetings for a single report.

In spite of the seemingly long extension to the report process, the time for inclusion of reports and papers to the Special Report is not actually extended by any great amount. Similarly, the time available to authors to add to writing and preparation time remains relatively short.

The meeting participants have started to identify gaps in the literature and a number of papers for GHGT 7 are to be prepared by participants. I was able to say a few words about GHGT 7 and the goal of peer-reviewing the papers as much as possible. The new, delayed timing on the IPCC Report will make it possible to incorporate peer-reviewed GHGT 7 literature. It will also give some leeway in the preparation of material for the Weyburn Monitoring and the Acid Gas Injection Projects.

The next meeting will occur after the First Order Draft has gone out for review. The TSU has a list of names for the review of the first draft and are collecting more – this I believe will be collated by the TSU and pared down to a reasonable number. At the next meeting, there will be a new group in the meetings, each subgroup will have two review editors to ensure effective treatment of the comments coming from expert reviewers. It will be after this that the final references can be added and the final round of reviews undertaken.

Conclusion

The process remains interesting, but frustrating to the authors. In particular, this is true for the authors that take their responsibilities seriously. The Coordinating Lead Authors for each chapter have a considerable burden placed on them to try to meet the needs of the IPCC process as well as provide direction to a diverse group of authors. This task will become more burdensome as the review editors are added to the chapter groups.

The cross-cutting aspect is similarly problematic in that chapter groups lose people to the cross-cutting discussions periodically. The way cross-cutting issues are dealt with is iterative, requiring considerable patience by all concerned. It is also not an easy task with the text generally incomplete. The useful component of the cross-cutting exercise has been to force authors to develop concise definitions for terms.

APPENDIX F - FRAMEWORK FOR INTERNATIONAL PROJECT COLLABORATION AND SCIENTIFIC EXCHANGE: PART B: INTERNATIONAL SECONDMENT

Part B: Boilerplate agreement for secondment of Scientists and Engineers to other countries, prepared by Bill Gunter, Alberta Research Council for discussion with Peter Cook and Andy Rigg of the Australian CO_2 CRC

DRAFT

Proposed Cooperation Agreement between

CO_2 CRC Pty Ltd

(CRC)

-and-

Alberta Research Council Inc.

(ARC)

List of Definitions:

Visit – Scientist/Engineer employed by Parent Party transfers to Host Country

Visitor – the scientist/engineer who leaves the Parent Country to work on projects in the Host Country

Host Country – Canada or Australia; the country hosting the Visitor

Parent Country – Canada or Australia; the country which the Visitor is from

Host Party – ARC or CO_2CRC; the party which the scientist/engineer Visits

Parent Party – ARC or CO_2CRC; the party which the scientist/engineer is employed by prior to the Visit

WHEREAS:

A. CRC is a ……………………………

B. ARC, is one of the leading research councils in Canada, is committed to fostering the conduct of research in natural sciences and engineering that may be beneficial to the development of resources or industry that enhances the quality of life of Albertans and has an active program on CO_2 Capture and Geological Storage;

C. Pursuant to earlier letters (see Attachment A) supporting collaboration between ARC and GEODISC, and ARC and the CO_2CRC, each of the ARC and CRC believes that it would benefit from collaboration in CO_2 Capture and Storage, and that an appropriate mechanism to accomplish this is by movement of technical people between the two programs.

Each of ARC and CRC agrees with the other as follows:

Article 1 – Objectives

1.01 **General Statement:** The general objective of this Agreement is to move expertise between the two programs on CO_2 Capture and Geological Storage by sending experts from one organization to the other for a Visit where they would work on the other organization's projects to accelerate the development of technology. That general objective will be pursued by:

(a) the establishment of a Nominations Committee as provided in Article 2;

(b) the establishment of a process and conditions for the movement of scientists and engineers as provided in this agreement.

Article 2 – Nomination Committee

2.01 **Appointments:** Each party will appoint two individuals, each being a Nomination Appointee to coordinate the relationship contemplated in this Agreement. Appointments will be made by written notice identifying the person so appointed. A party making an appointment pursuant to this Agreement may replace any such Nomination Appointee by written notice to the other party.

2.02 **Nomination Committee:** The Nomination Appointees, together with such individuals as the parties may mutually agree, will constitute the Nomination Committee. The Nomination Committee will have a Chair . The Nomination Committee will communicate by e-mail and phone (in a 6 month cycle) to consider scientists and engineers for nomination for Visit. In addition to any specific responsibilities provided for in this agreement, the Nomination Committee will make recommendations to the parties on the implementation, continuous improvement, and enhancing of the effectiveness of the relationship contemplated in this Agreement.

2.03 **Decisions and Procedures:** Decisions may be made by the Nomination Committee only through unanimous agreement of the representatives of each of ARC and CRC. The Nomination Committee may establish rules for making decisions on the conduct of the business of the Nomination Committee and on the acceptance of a scientist or engineer for a Visit. Those rules will provide for the Chair of the Nomination Committee to serve for a one year period, and to alternate between an ARC Nomination Appointee and a CRC Nomination Appointee.

Article 3 – Statement of General Principles

3.01 Movement of Scientists and Engineers between CO_2 Capture and Geological Storage technology programs in Canada and Australia benefits both the Parent and Host Party by transferring expertise and knowledge between countries in an area which is very important for both countries in reduction of GHG Emissions and development of each countries National Oil and Gas Industry.

3.02 Names of scientists or engineers from each country who are experts in CO_2 Capture and Geological Storage will be proposed by the parties to be on a Nomination List prepared by the Nomination Committee for consideration of a transfer to the other country.

3.03 The merits of each proposed Visitor in relation to CO_2 Capture and Geological Storage Technology will communicated by the Parent Party to the Host Party.

3.04 The Host Party will search for a Project on CO_2 Capture and Geological Storage (= Project) in the Host Country that the proposed Visitor could make significant contributions to.

3.05 If a Project is not found, then the proposed Visitor will be dropped from the Nomination List and not considered further,but may be re-considered in successive lists should a project arise.

3.06 If a Project is found, then suitable funding will be identified by the Host Party to cover a minimum of 1 year.

3.07 Providing suitable funding is found for the Visitor, he/she will be offered a position with the Host Party of the Host County, and he/she will be required to sign certain documents of employment with the Host Party to accept the position in the Host Country. It is up to the individual to seek a work permit in the Host Country – assisted where possible by the Host Party.

3.08 It is deemed that a shorter Visit than one year are not productive for the Host Country.

3.09 Since the Visitor will be an expert in CO_2 Capture and Geological Storage, it is deemed that he/she can not totally abandon existing projects of the Parent Party. Therefore, provision has to be made for he/she to work on these projects while in the Host Country.

3.10 Up to 50% of the work time of the Visitor in the Host Country may be spent on Parent Party projects if the Parent Party pays for the Visitor's time, costs and overheads.

3.11 Visitors are chosen on an opportunity basis. It is not required that each of the two countries receives an equal number of Visitors.

3.12 Any IP generated by the Visitor belongs to the Host Party unless it can be demonstrated that the IP was partly or fully developed prior to the transfer taking place or during the time the Visitor was working on a Parent Party project; then the Parent Party has part or full ownership. *[A different suggestion is that any IP the Visitor generates while in the Host Country is shared between the Parties]*

3.13 Confidentiality requirements pertaining to the Visitor are to be specified by the Host Party while the Visitor is being under the employment of the Host Party.

3.14 Publicity releases are determined by the Host Party with the caveat that where possible full recognition should be given to Parent Party for providing the Visitor.

3.15 At the end of each Visitor's assignment in the Project in the Host Party, a short report is to be prepared and filed with the Nomination Committee.

3.16 The Consuls of the Parent Country located in the Host Country are to be kept aware of this cooperation between the two parties.

3.17 The target for the first Visitor transfer to Australia is to be the summer of 2004 prior to the 3rd Carbon Sequestration Leadership Forum meeting which is being hosted by Australia.

3.18 The target for the first Visitor transfer to Canada will be decided by the Nomination Committee.

Article 4 – Visitor Considerations

4.01 Salaries of the Visitor are based on Host Country salary scales.

4.02 The Host Party will pay reasonable travel expenses for one trip from the Parent Country to the Host Country and return to coincide with the beginning and end of the Visit. This may include the family of the Visitor.

4.03 In cases where maintenance of a residence in the Parent Country is required, a reasonable living supplement is to be paid by the Host Party to the Visitor while in the Host Country working on a Host Country Project.

4.04 Overheads of the Host Country are to be paid are the responsibility of the Host Party

4.05 No overhead will be paid to the Parent Party

4.06 Holidays will be provided to the Visitor as appropriate to the rules and regulations of the Host Country

4.07 The location of the Visitor in the Host Country will be decided by the Host Party based on the nature of the Project, and will not necessarily be at the Host Party's Institution.

4.08 Appropriate facilities will be provided for the Visitor in the Host Country including but not limited to office, phone, computing facilities and laboratory space if required.

4.09 Opportunities for the Visitor to network in the Host Country will be reviewed by the Host Party and encouraged. Where appropriate these will be provided and paid for by the Host Party

…………………………………….

IN WITNESS WHEREOF, the parties have executed this Agreement as of the day and year first above written.

Alberta Research Council, INC **CO_2 CRC PTY LTD**

Per: **Per:**

APPENDIX F - FRAMEWORK FOR INTERNATIONAL PROJECT COLLABORATION AND SCIENTIFIC EXCHANGE PART C: INTERNATIONAL COLLABORATION

Part C: Example of international collaboration by Bill Gunter, Alberta Research Council

International Participation

The Alberta Research Council (ARC) is supporting the research for a project which will inject quantities of CO_2 into coal, in order to determine the optimum method to sequester coal in seams and to observe the method of injection for coal bed methane recovery. Prior to and during the project, three dimensional (3-D) seismic and possibly down-hole VSP and tomographic surveys will be recorded, to establish the migration paths of the CO_2 through the coal over the injection period.

Such projects as this benefit from the technical support provided by all researchers, including international research bodies where they can offer techniques which are not readily available to Canadian researchers. It is desirable to establish a research linkage of Canadian researchers with other researchers from Australia and Japan, who are equally involved in similar projects in their countries, and have a capability not available to the Canadian researchers. In addition, if funding for such external research can be achieved without affecting the ARC project funds, then the equal exchange of both data and technologies will benefit all researchers.

Rock physics characterization of CO_2 injection into coal

International Research Parties

Curtin University- Curtin University Geophysics and Petroleum Engineering Departments in Perth, Australia, is a member of the CO_2CRC. As part of the CO_2 research work of the Geophysics department, a large pressure chamber has been built which allows physical models to be injected into, at pressures up to 8.5 MPa, while both direct transmission and 3-D reflection ultrasonic seismic data is recorded over the model. The models may be injected with CO_2 to allow the seismic response to be understood, as well as the 3-D image of migrating fluids to be mapped. CO_2CRC has a Program which has funding for international projects, if they are seen to be supportive of Australian operations. This mechanism has been successfully used to allow the researchers to visit Europe and thereafter reprocess 3-D volumes from the Sleipner injection site.

Previous work done for BHP Coal in 1994 by Curtin Geophysics, showed that seismic attributes could be developed to map methane sweet-spots in coal seams. Similar work could be done in the pressure chamber for comparison with field recorded 2-D or 3-D seismic data from the proposed Canadian injection site. In addition, Curtin has a strong team involved in rock physics, which is developing technologies to support the understanding of the changes in the seismic response as a function of CO_2 injection.

Research Institute for Innovative Technologies for the Earth (RITE)- RITE in Kyoto Prefecture, Japan has funded the development of technologies to understand the migration of fluids through coal seams, and in particular, understand the stresses and swelling of coal as a result of injection of CO_2. The facilities to perform this includes the ability to take coal cores to high pressure and inject them also at high pressure while pulsing the cores with both compressional and shear waves. The direct arrivals of such waves provides an indication of permeability changes as a function of cleat variations and the onset of swelling due to CO_2 adsorption. There is strong potential for using compressional and shear wave recording for the imaging (through tomographic methods) of coal core variations as a result of the injection of CO_2 under different pressure conditions and CO_2 phases, and to apply that knowledge to understanding field data from the Canadian injection site.

Kyoto University Petroleum Geophysics/Engineering- The Kyoto University in Japan over the last two years has been developing the capability to understand and simulate fluid flow through numerical models of various rock matrices. In particular, they are able to model fluid propagation direction as a function of coal cleat and throat-rugosity relationships. They have been working with RITE to simulate fluid transport models and their relationship to patchy saturation and clay swelling. A strong research relationship exists between RITE and Kyoto with both data and funding to support model development.

Plan

It is proposed that the three parties (Curtin/RITE/Kyoto) work together with the Canadian researchers (University of Calgary, University of Alberta, Alberta research Council) to understand the changes in rock properties to allow the future mapping, using seismic methods, of the migration and phase of injected CO_2 within coal seams. This would provide invaluable information for the future monitoring of CO_2 movement and its phase to allow enhanced understanding and security of injection operations.

Their particular areas of research would be:

Curtin – Physical simulation in the pressure chamber, of coal injected with CO_2, obtaining the seismic response, inversion, and development of attributes for field mapping CO_2 migration. Application of these attributes to field data provided by University of Calgary.

Contacts: Prof Brian Evans (evans@geophy.curtin.edu.au) and Prof Don Lawton (lawton@ucalgary.ca).

RITE – Physical simulation of compressional and shear wave data using whole cores of coal obtained from the field, obtaining estimates of Poissons Ratio and other geophysical/geological data which would be provided to both Calgary and Curtin.

Contact: Dr Ziqiu Xue (xue@rite.or.jp) and Prof Rick Chalaturnyk (rjchalaturnyk@ualberta.ca)

Kyoto – Numerical simulation of CO_2 migration through a coal matrix, and the effects of changes in mechanical and geophysical coal properties as the fluid passes in its different phases, through the matrix.

Contact: Prof. Toshi Matsuoka (matsuoka@earth.kumst.kyoto-u.ac.jp) and David Law (law@arc.ab.ca).

APPENDIX G - TECHNOLOGIES AND KNOWLEDGE BASES NEEDED FOR IMPLMENTATION OF GEOLOGICAL STORAGE OF CO_2

By Bill Gunter, Alberta Research Council

The Canadian Technology Roadmap will be a "living document" with the framework and details evolving as new data, information and opportunities are identified based on piloting.

Piloting is the driver for Technology Development and Performance Programs in Geological Storage. One could draw a parallel to the hugely successful Underground Test Facility which was funded by AOSTRA, an Alberta government organization and was instrumental in developing and commercializing novel in situ oil sand recovery technologies. Piloting would focus on storage engineering for oil reservoirs, gas reservoirs, CBM reservoirs and saline aquifers. Pilots would bring the technology to application from the technology development areas. Successful pilots would lead to commercial development where the cost of pipelining would become an important consideration. In support of the Pilot Projects, a series of complementary programs and technology development areas are envisioned that when fully integrated throughout the pilot project phases will provide a complete, synthesized assessment of the potential for a geological storage industry in Canada. Pilots fall into the following categories:

- Enhanced Gas Recovery - A relatively immature field due to the high depletion by primary recovery methods.
- Enhanced Oil Recovery - A mature field but the focus needs to be changed to co-optimization of production and storage. A special case is gas-over-bitumen.
- Enhanced Coalbed Methane Recovery - An immature field that needs piloting. Gas shales fall in the same category but are less advanced.
- Depleted Hydrocarbon Reservoirs - Examples of storage in these reservoirs are found in acid gas injection and natural gas storage. Long-term issues still have to be addressed.
- Saline Aquifers - A very different storage reservoir. It is the only reservoir type where injection pressures substantially exceed reservoir pressure. Experience is based on oil field water disposal and acid gas injection. Aquifers have the biggest capacity for storage but are the least characterized of all the reservoirs.
- Methane Hydrate Reservoirs – CO_2 hydrates are more stable and if CO_2 is injected into a methane hydrate reservoir, it will displace the methane hydrate by capturing the water from the methane hydrate and releasing the methane. The issue is low permeability because the hydrates are solids filling the pore spaces.
- Mineral Surface Storage – Crystalline ultramafic and mafic rocks contain basic minerals which are unstable with respect to carbonate minerals in a CO_2 atmosphere. These crystalline rocks outcrop in areas between sedimentary basins. They are of low permeability but can be mined at the surface and crushed and processed in a chemical reactor under a CO_2 atmosphere to form carbonate minerals. Issues are kinetics of reaction and the large size of such

operations. Mineral storage in deep sedimentary reservoirs will occur naturally if basic minerals are present.

The Technology development areas (regional scale geological and hydrogeological characterization, reservoir characterization, existing well characterization, well technology, storage engineering, containment engineering, measurement and monitoring, mitigation and remediation technology, and pipelining and surface facilities) and Policy and Performance areas (regulation and outreach, life cycle and economics, and risk and performance assessment) are briefly described, and important technologies and knowledge bases to be developed and tested through piloting are identified under these areas in the remainder of this document.

Technology Development

Regional-Scale Geological and Hydrogeological Characterization

Geological and Hydrological Regional-Scale Characterization: includes the regional-scale geology and hydrogeology for selected areas, as well as around individual storage units (reservoirs, deep aquifers, coal beds) through detailed interpretation of geology, geochemistry, geomechanical and geothermal regimes, deep hydrogeology and shallow groundwater. This is the broader box that contains the storage unit and controls the migration of CO_2 if and when it migrates and/or leaks from the storage unit.

Technologies and knowledge bases to develop

- Standard methodology for application across the country
- Subsurface and near-surface geological and hydrogeological models of the containment volume
- Properties and characteristics of overlying and underlying barriers (e.g., porosity, permeability, strength, mineralogy, etc.)
- Site assessment capability: potential leakage paths through the barriers and migration along the bounding aquifers
- Migration and flow modelling of CO_2 in the underlying and overlying aquifers before injection
- Groundwater integrity
- Natural analogues
- Industrial analogues which are leaking, or have leaked and been mitigated

Reservoir Characterization

Characterization of the reservoir: hydrocarbon reservoir, deep aquifer or coal bed. This is the primary storage container for the CO_2 and must be quantified in terms of: heterogeneity, permeability, pore space, reactive mineralogy, weaknesses in the caprock seal as a function of pressure, properties of resident (native) fluids.

Technologies and knowledge bases to develop

- Methodology and approaches to site characterization
- Screening criteria and models for matching storage reservoirs with CO_2 sources
- Capacity assessment
- Assessment of potential leakage paths through the caprock

- Natural and industrial analogues
- Properties and characteristics of reservoir, aquifer, coal beds and confining rocks (e.g., porosity, permeability, strength, mineralogy, adsorption isotherms, etc.)
- Properties and characteristics of reservoir and aquifer fluids (e.g., density, viscosity, heat capacity, thermal conductivity)

Existing Well Characterization

Existing Well Characterization: this would allow identification of induced leakage paths, and, in addition, future susceptibility to leakage through abandoned wells must be assessed. Independently, all aspects of injection and production wells and abandonment of wells must be improved, particularly abandonment if the wells are to survive for several centuries.

Technologies and knowledge bases to develop

- Leak rate models
- National database of abandoned oil and gas wells
- Database of waterwells for near surface leakage
- Assess well failures
- Evaluation criteria for integrity of old wells

Well Technology

Developments in drilling allow better access to reservoirs. A review of the past practices for well abandonment will be made with a view to stability of the casing and cements, and bonding between the cement, formation and casing. New materials and procedures for completions and abandonment are needed so that the wells will not leak over the long term.

Technologies and knowledge bases to develop

- Alternative injection well configurations and procedures for maximizing CO_2 injection (e.g. horizontal and multi-lateral wells, hydraulic fracturing)
- Long-term cement integrity
- Low-cost reliable well abandonment procedures
- Corrosion control and better well materials (e.g. cements, steel coatings)
- Use of pre-existing wellbores
- Injection process technology

Storage Engineering

Storage and Reservoir Engineering: focuses on maximizing the CO_2 storage and petroleum production potential of the reservoir over the long term being cognizant of the economics. Initial pilot projects on CO_2 storage will be focused on "Added Value" projects such as EOR and ECBM. These projects may be commercial in their own right and allow us to tag on to them for experience and more importantly for technology development in monitoring, verification and the safety of geological storage. EOR is a mature technology only if the options to maximize CO_2 storage are not considered. On the other hand, ECBM is a developing technology that may be commercial without considering geological storage of CO_2. A different type of opportunity exists in acid gas disposal where commercial scale acid gas injection is occurring because of the existing regulatory regime and CO_2 is already being stored. Opportunities to use the acid gas for enhanced gas recovery (EGR, EOR or ECBM) may exist. There are technology issues with all three options that have to be addressed. Don't join in the "Mouse Parade", aim for the breakthrough technologies.

Technologies and knowledge bases to develop

- Properties and behaviour of CO_2 and CO_2 mixtures (e.g. N_2, H_2S, SO_2) (gas versus supercritical)
- Geochemical research of effects of CO_2 on reservoir properties
- Trapping of CO_2 by precipitation of carbonate minerals (e.g. kinetics) both on the surface and in the subsurface
- Numerical reservoir models that handle the reservoir's geotechnical properties
- Swelling behaviour in coals due to various waste gas sorption
- CO_2 storage optimization
- Methanogenesis
- Injection of CO_2 into methane hydrate reservoirs
- Injection of CO_2 into aquifers in Artic to form hydrates
- Identify, characterize and test novel geological settings for CO_2 storage and "value-added" hydrocarbon production (e.g. ECBM, EGR)
- Pressure maintenance with CO_2 (e.g. eliminate waterflood, gas-over-bitumen)
- Drycleaning (i.e. CO_2 soak) instead of continuous injection
- Recycling of CO_2 as it affects the lifetime of CO_2 in the reservoir.
- Geochemical research of effects of CO_2 on caprock integrity
- Geomechanical research on effects of stress changes (e.g.. reservoir pressure build up due to injection) on caprock integrity

Containment Engineering

Containment Engineering is the characterization and assessment of CO_2 trapping and leakage systems outside the storage reservoir.. This subject is closely related to and integrates with other technologies such as reservoir characterization, well technology and well characterization, storage engineering, monitoring and mitigation technology.

Technologies and knowledge bases to develop

- Migration and flow modelling of CO_2 in the underlying and overlying aquifers, aquicludes and aquitards in the event of a breach in the caprock or well leak
- Numerical aquifer models that handle two phase flow
- Good material balances
- Groundwater integrity – negligible contamination of potable water resources
- Induced seismicity – in the reservoir, caprocks and underlying strata
- Mechanical, thermal and transport properties of the bounding caprocks and underlying strata
- Direct and indirect mapping of what could become critically stressed faults during injection operations
- Effect of injection pressure or storage pressure above or below hydrostatic pressure
- Prediction of fault hydraulic conductivity and reactivation risk as a function of stress changes due to injection
- Storage permanence – quantitative predictions of leakage rates

- Well logs and core data for caprocks
- Well test methods for low permeability caprocks

Measurement & Monitoring

Monitoring and Verification: aspects of technology that must be addressed are frequency of monitoring, length of monitoring, spacing of monitoring tools, vertical depths of monitoring from the reservoir to the surface and development of new monitoring tools as well as safety and risk, standards and protocols. Monitoring technology will input into the regulatory framework. There's no "canary cage" available for detecting CO_2 leaks.

Technologies and knowledge bases to develop

- Monitoring systems for detecting and quantifying the amount and rate of leakage
- Tracers that can be reliably monitored from the subsurface and surface (e.g. isotopic, in situ, noble gases, odours, colorimetric).
- High resolution seismic and non-seismic methods for identification of the CO_2 plume (e.g. surface through borehole seismic, microseismic and crosswell tomography, electromagnetic, gravity, tiltmeters)
- Geomechanical monitoring technology
- Airborne monitoring
- Groundwater monitoring
- Low-cost, near-surface technology for the presence of CO_2 (e.g. eddy covariance)
- Soil carbon measurement (e.g. soil gas)
- Remote sensing of above ground leaks (e.g. by changes in vegetation)
- Observation wells
- Well-based monitoring technology (e.g. well logs – NMR, well testing – pressure transients)
- Wireless technologies
- Spatial & temporal resolution

Mitigation and Remediation Technology

Mitigation technologies are designed to block CO_2 leaks from the storage reservoir, once they are discovered and to remediate the damages.

Technologies and knowledge bases to develop

- Migration and flow modelling of leakage pathways including subsurface, land surface and atmospheric models of CO_2 migration and dispersion
- Leaking wellbores
- Intelligent, self-activating control systems
- Environmental remediation

Pipelining & Surface Facilities

Pipelining and Surface Facilities: CO_2 pipelines exist as do CO_2 pumps. Focus would be on substitute materials to lower the costs.

Technologies and knowledge bases to develop

- Acceptable types and levels of impurities in the CO_2 stream
- Pipeline materials
- Compressor technology
- Dehydration of CO_2
- Treatment of recycled CO_2
- Use of existing natural gas pipeline with blended or slugged NG and CO_2 (need portable separation technologies)

Policy & Performance

Regulation & Outreach

Education/Outreach: The notion of capturing and sequestering carbon dioxide and other greenhouse gases is relatively new, and many people are unaware of its role as a greenhouse gas reduction strategy. Increased education and awareness are needed to achieve acceptance of carbon storage by the general public, regulatory agencies, policy makers, and industry and thus enable future commercial deployments of advanced technology. The education/outreach program will seek to engage NGO's, federal, provincial, municipal and local environmental regulators to raise awareness of geological storage

Regulatory/Legal Framework: Western Canada has one of the better regulatory frameworks for production of oil and gas. These have to be modified to address the long-term issues inherent in geological storage. Policy has to be developed first as a precursor to the regulations.

Technologies and knowledge bases to develop

- Supporting regional activities to identify and assess CO_2 source-transportation activities-storage activities
- Broaden working with environmental non-governmental organizations to further define "learnings" required to assure environmental acceptability
- Strive for consistency in technology (e.g. use "storage" not "sequestration". "Sequestration" is the combination of "Capture" and "Storage") to enhance public understanding
- Assessing critical crosscutting issues such as measurement and verification of the amounts of carbon stored
- Exploring novel concepts that may lead to entirely new pathways
- Encourage market-based incentives over regulatory approach (e.g. Feds/Provinces set up a capture and transport facility that sells pure CO_2, splitting cost between public and private sectors)
- Implimentation of incentives to encourage emission trading – ensure level playing field
- Auditing rules for stored CO_2
- Establish rules for ownership of pore space, credits (i.e. capturer or end user of CO_2)
- Build on existing regulations for EOR, Gas Storage and Deep Waste Well Disposal

- Resolve conflict between national roadmap versus provincial regulations – require interprovincial standards and guidelines
- Continuing public outreach activity to provide information and education materials about carbon storage
- Standards for injection wells
- Standards for materials in contact with the CO_2
- Standards for pipelines and transportation
- Standards for assessment of storage reservoirs including aquifers
- Standards for assessment of storage security including caprock and overlying geological barriers/seals
- Modelling standards for geological, geochemical, geomechanical, hydrogeological and multiphase flow/diffusion
- Standards for abandonment procedures and practices
- Standards for monitoring on the surface and in the subsurface in the short and long terms. Develop baseline protocols for monitoring which will increase efficiency, reduce the economic burden and increase public acceptance.
- Financing needs in the short (i.e. during injection) and in the long term (i.e. after abandonment) including insurance and ownership
- Standards for occupational and environmental safety
- Standard for long term emergency preparedness
- Long term management responsibilities
- Public goodwill – cannot afford to ignore stakeholder relationships

Risk and Performance Assessment including HSE

Risk/Performance Assessment. Risk models need to be established for the leakage of the CO_2 (slowly and rapidly) from the storage reservoir through breaks in the seals and along well bores both in the short (during the injection period) and in the long (over the storage period) term. Safety issues and verification strategies feed into the risk/performance assessment Risk is a function of both consequences and the probability of an occurrence. Probability is the difficult nut to crack..

Technologies and knowledge bases to develop

- Establish a framework of global, operational and local risks further divided by short term and long term risks
- Adaptation of risk assessment methodology from natural gas storage and oilfield waste injection to geological storage of CO_2
- Define performance standards for geological storage of CO_2
- Identify safe and acceptable CO_2 leakage rates appropriate to each geological setting
- Comprehensive studies of natural CO_2 reservoirs and gas storage fields
- Integrated studies of natural seepage of CO_2 with reservoir simulation and basin modelling
- Safe, cost-effective CO_2 storage field development and operating practices
- Ecosystem flux models and health effects
- Safe and acceptable CO_2 leakage
- Risk of low level CO_2 exposures (e.g. health costs associated with a warmer climate allowing infiltration of non-native diseases)

- Contamination or displacement of subsurface resources (e.g. water, coal)

Life Cycle and Economics

Life Cycle Analysis. The program will focus on the question "What is life cycle analysis in the context of geological storage" to analyze in the evaluation of GHG emissions throughout the full product or service system life cycle.

Economic Modeling. Economic models have to evolve to handle environmental and health costs, keep account of avoided CO_2 as well as changing regulations. The risk and liability for leakage should also be part of the model.

Technologies and knowledge bases to develop

- Determine a value for CO_2 under various future scenarios
- Integrated economic model which evaluates the geological storage of net CO_2 through capture, purification, compression, pipelining and storage in geological media in depleted oil & gas reservoirs, in aquifers and in enhanced recovery projects
- A unique, web-based trading platform developed to find market-based solutions to help reduce CO_2 emissions to the atmosphere; by facilitating the logistics necessary to bring Sellers, Buyers and Auxiliary Service Providers (purification, compression, storage and transportation) together for the purpose of concluding successful transactions; augmented with an accurate documentation tracking system to monitor volumes traded; crystallizes the background, purpose and global business platform required to encourage the reduction of CO_2 emissions to the atmosphere while facilitating the concept of shared costs between stakeholders;
- A database linking to pertinent facts, figures and events concerned with capture and storage
- Require market based incentives (e.g. emission trading)
- Include environmental and health costs

Competiveness of Canadian CO_2 Storage R&D Technology Areas

R&D in Canada is strong in the area of regional scale geological and hydrogeological characterization. Canada's position in R&D in the areas of reservoir characterization, existing well characterization, well technology, storage engineering, containment engineering, measurement and monitoring, mitigation and remediation technology, and pipelining and surface facilities is favorable. Some technologies in these technology areas are site specific while others are not. In the future the transferable technologies will be identified.

Time for Development of Technology Areas to Maturity

In the period to 2010, the technology areas of regional scale geological and hydrogeological characterization, reservoir characterization and storage engineering will achieve maturity. Between 2010 and 2020, short term monitoring, short term mitigation and remediation, well characterization, containment engineering and pipelining will reach maturity. Beyond 2020, long term monitoring, long term mitigation and well technology will mature.

Commerciality Pathways

There is a mismatch between capture and storage projects in going from pilot to demonstration to commercial activities in terms of amounts of CO_2 captured and stored.. Capture demonstrations are generally much larger. Storage pilots are distinguished by their non-commercial spacing while demonstrations may have the same number of wells but are on a commercial spacing. Pilots test the technology while demonstrations test the commerciality. Each storage pilot or storage demonstration involves similar rates of CO_2 injection, on the order of 50 to 200 tonnes CO_2/day. In Canada, there is one ECBM pilot (CSEMP), and four EOR pilots (yet to be announced by ADOE). There are two commercial EOR operations (PennWest at Joffe at 200 tonnes/day and EnCana at Weyburn at 5000 tonnes/day) and 42 commercial acid gas injection operations of small scale. All of these offer opportunites for tagon testing and development of storage technologies as has been done at Weyburn. In addition, sites for pilots must address geological variability (e.g. rock type, rock strength, reservoir type, reservoir complexity, reservoir depth & thickness, reservoir poristy & permeability, reservoir temperature & pressure, faults, abandoned wells, formation water composition, and hydrocarbon composition). Therefore, evaluation of additional potential sites must be done that address different aspects of geological variability for piloting storage in the Western Canadian Sedimentary Basin. Many of these geological variables are duplicated between fields and basins. One field may host both shallow and deep reservoirs, several coal horizons and multiple aquifers (defined as stacked reservoirs). Identifying these sites allows collapsing the number of sites necessary to address all the geological variables for successful storage. These remaining opportunities can be classified into isolated single/stacked sweet spots (defined as single or stacked reservoirs having a high potential for commerciality but are isolated from readily available CO_2), or integrated single/stacked sweet spots (defined as single or stacked reservoirs having a high potential for commerciality and having existing infrastructure for CO_2 delivery). The site selection should be based on the intent to build a market for CO_2 storage with the involvement of industry. The most promising integrated stacked sweet spots are Wabamum, Edmonton-Fort Saskatchewan and Red Deer-Joffre.

Sources of Information and Related International Activities

FutureGen

(www.netl.doe.gov/coalpower/sequestration, www.fe.doe.gov/coal_power/sequestration)

US integrated Sequestration and Hydrogen Research Initiative: Design, construct and operate a nominal 275-megawatt (net equivalent output) that produces electricity and hydrogen with near-zero emissions. The size of the plant is driven by the need for producing commercially-relevant data, including the requirement for producing one million metric tonnes per year of CO_2 to adequately validate the integrated operation of the gasification plant and the receiving geologic formation. By 2020, the FutureGen project will produce electricity with less than a 10% increase in cost compared to non-sequestered systems, produce hydrogen at $4.00 per million Btu (wholesale) equivalent to $0.48/gallon of gasoline, or $0.22/gallon less than today’s wholesale price of gasoline.

Regional Sequestration Partnerships

(www.netl.doe.gov/coalpower/sequestration, www.fe.doe.gov/coal_power/sequestration)

US program to engage local government agencies and non-governmental organizations, along with the research community and private sector participants, in a number of partnerships centered in areas of the country with potential for CO_2 capture and storage.

International Energy Agency (www.ieagreen.org.uk)

The Greenhouse Gas Research and Development Programme evaluates greenhouse gas mitigation technologies, and holds an International Conference every two years.

The Carbon Capture Project (www.co2captureproject.org)

The CCP aims to develop new breakthrough technologies to reduce the cost of carbon dioxide separation, capture, transportation and sequestration from fossil fuel streams by 50% for existing energy facilities and by 75% for new energy facilities by the end of 2003 compared to currently available alternatives.

The Sleipner Project (www.ieagreen.org.uk/sacshome.htm)

Roughly one million metric tonnes per year of CO_2 from a natural gas processing platform in the North Sea is being captured and injected into the Utsira saline clastic aquifer by Statoil. The SACS (Saline Aquifer CO_2 Storage) project uses a robust measurement, verification and transport modeling activity to compliment and enhance the injection project.

Weyburn Monitoring Project (www.ieagreen.org.uk/weyburn4.htm)

Injection of 5000 tonnes/day of CO_2 into the Midale carbonate oil reservoir in an EOR scheme by EnCana. A parallel monitoring program is being carried out under the direction of PTRC.

Planned Projects

In Salah (BP), Snohvit (Norway, Statoil), Teapot Dome (US), Gorgon (Australia, Chevron Texaco)

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Input is gratefully acknowledged from Stefan Bachu, David Law, Pat McLellan, Malcolm Wilson, Don Lawton, Michelle Heath and Rick Chalaturnyk

APPENDIX H - FINANCIALS

By Rick Chalaturnyk, University of Alberta and Sam Wong & Bill Gunter, Alberta Research Council

Top Level Finances

A high level budget for the CANiSTORE is proposed in Table H.1, details are discussed later. The cost of a CANiSTORE pilot project is estimated based on a five spot pilot at approximately $18 million dollars if design, capital, operating and MMV (measurement, monitoring & verification) costs are included. In support of other field projects already in operation (e.g. pilot, demonstrations, commercial which are not part of CANiSTORE), costs are budgeted in the category "external project collaborations". Science & technology programs, and policy & performance programs have individual budgets which are to suppport field pilots, demonstrations or commercial projects whether the field operations are part of CANiSTORE or the field operations are external.

CANiSTORE Budget ($106M)	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
External project collaborations	1.50	3.00	3.00	3.00	3.00	3.00	3.00	5.00	5.00
Science & technology programs*	0.25	2.00	3.00	3.00	3.00	3.00	3.00	1.50	1.50
Policy & performance programs	0.25	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Manage/operate CANiSTORE	0.25	0.50	0.50	0.50	0.50	0.50	0.50	0.25	0.25
HCGS pilot design	*0.10*	*0.80*							
HCGS pilot construction		*5.00*	*4.50*						
HCGS pilot operation			*0.70*	*1.30*	*0.70*				
HCGS monitoring & verification		1.50	2.00	0.60	0.50				
Design of Commercial Demo					*0.50*	*0.75*			
Commercial Demo Execution						*10.00*	*10.00*	*3.00*	*3.00*
CANiSTORE Grand Totals ($M)	**2.4**	**13.3**	**14.7**	**9.4**	**9.2**	**18.3**	**17.5**	**10.8**	**10.8**

* includes basin characterization programs of the geological surveys;
Note: italics underlined indicates costs paid by industry

Table H.1 Budget components for CANiSTORE

Note that the budget for the geological surveys top-down basin evaluation is included in the CANiSTORE budget. However, perhaps this part of the budget should not be considered as part of the CANiSTORE as the autonomy of the surveys should be protected by remaining 100% under government control.

The science & technology development program is budgeted at $3 million per year (including basin evaluation) and the policy & performance programs at 1 million per year. Management and support is budgeted at $0.5 million per year at approximately 4% of the total budget.

External projects are budgeted at $3million per year, increasing to $5 million over the last two years (Table H.1), which reflects investment in external projects that are being commercialized.

As stated before, it is anticipated that a field pilot project will be undertaken by CANiSTORE. It is also anticipated that this project will evolve into a commercial demonstration. Planning and execution for the commercial demonstration would start in earnest in approximately 2008 and a proposed budget from the CANiSTORE is $27 million for 3 years of operation through 2012 of a four pattern demonstration involving 13 wells.

It is anticipated that the CANiSTORE program would be funded by both government and industry. While government would focus on the technology development, industry's focus would be on commercialization. Industry would pay for the pilot and commercial demonstration at a cost of $40 million to the end of 2012. Government would pay for the science & technology programs (including the MMV), the policy & performance programs, the external program collaborations, and for the management/operation of CANiSTORE. The government's share would be $66 million for an average of $7 million/year. The projected income for the centre is built around such assumptions. Some of this could be offset by the revenue stream developed by CANiSTORE (Figure H.1). There are both hard and soft revenues. The output of the early years of the Centre could be intellectual property, regional geological maps, capacity/utilization assessment and input into the regulatory framework. Internal commercialization revenue would be from the sale of emission credits, and enhanced oil and gas production sales from CO_2 injection in commercial projects such as gas over bitumen, enhanced gas recovery, enhanced coalbed methane, enhanced oil recovery, acid gas injection, depleted oil and gas reservoirs and saline aquifers. Government would benefit from enhanced oil and gas royalty streams, and pore space rental. Industry would benefit from sale of the enhanced oil and gas streams, and emission credits.

A More Detailed Budget for the HCGS pilot

Assuming that a site is chosen with substantial infrastructure such as in Alberta's Industrial Heartland (i.e. Fort Saskatchewan/Redwater – see Appendix E) there are many possibilities for a CANiSTORE field pilot (for example, enhanced oil recovery (EOR), enhanced coalbed methane recovery (ECBM), and deep saline aquifer CO_2 storage). In addition, multiple reservoir access through a single well may also be possible in the area. In order to demonstrate early success, a pilot project that has the best chance to become commercial should be chosen. An EOR project would be a good candidate because of the depleted oil fields in the area. Below, an estimate of cost for performing such a pilot is described.

The costs of an EOR pilot project depends on a number of factors, for example, existing infrastructures available, depth of the reservoir, cost of CO_2, CO_2 utilization rate and recycle, etc. In the Industrial Heartland, typically the oil-bearing zone is located at about 1,000 m, so drilling costs will not be too excessive. The pilot project will likely be an inverted 5-spot (four producers and one injector), with a relatively small well spacing, perhaps 40 acres. The smaller well spacing is preferred so that reservoir response can be evaluated within one to two years of CO_2 injection.

The first decision for installing a CO_2 EOR pilot is that the reservoir must be amendable to a CO_2 miscible flood. The second decision is the economics of such a scheme. Assuming that two existing wells with good production history are available for this 5-spot pilot, the only additional wells that need to be drilled are one injector and two more producers. Other surface facilities required include oil water separator, stock tanks, produced water disposal, recycle compressor and the concrete pad.

For CO_2 services, assuming a CO_2 utilization performance of 10 MCF/bbl gross and 5 MCF/bbl net, the CO_2 injection rate will probably be in the range of 50 – 75 tonne per day for the single injector well. A number of high purity CO_2 sources are available in the Industrial Heartland area. Assuming that the CO_2 can be made available at no cost to the pilot project, the only cost incurred to the project will be the dehydration and compression cost of bringing the CO_2 to site. The capital cost of all the surface facilities which include the wells, dehydration, compression, recycle compressor, oil water separator, stock tanks and CO_2 tanks is estimated at about $ 9.5 million. It is also estimated that the pilot design would cost about 10% of the capital cost or about $ 0.9 million. The factor cost assumptions are listed as the following:

Capital Costs for Pilot	**Unit Cost**	**Total Cost**
Pilot design	$900k	$900k
Well drilling and completion (3)	$700k/well	$ 2,100k
Well workovers (2)	$190k/well	$ 380k
CO_2 dehydration and compression (50 t/day to 15.5 MPa)		$ 2,100k
Surface facilities including oil separator, stock tanks, recycle compressor, etc.		$ 4,900k
Grand Total Capital Costs		**$10,380k**

For the pilot operation, it is assumed that CO_2 injection will be continuous for two years. Initially the CO_2 will be drawn primarily from the CO_2 supply, however, as CO_2 breaks through and the CO_2 recycle will become more prominent, the draw from the CO_2 supply will be much lower at a later time. As this project is highly research orientated, a higher provision of data analysis and reporting is included in the operational cost. The operational cost is $ 1.3 million per year as tabled below:

Pilot Operating Costs	**Unit Cost/year**	**Total Cost for two years**
Wells (five)	$45k/well	$450k
Source CO_2 compression & dehydration	$228k	$456k
Recycle CO_2 compression & dehydration	$170k	$340k
Oil separation & water disposal	$120k	$240k
Labor (3 shifts to cover a 24 hr day)	$100k	$600k
Engineer (full time)	$200k	$400k
Manager (½ time)	$100k	$200k
Grand Total Operating Costs		**$2,686k**

Measurement and monitoring has been discussed in Appendix B and the costs have been taken from there and adjusted for the greater depth. The costs shown below are for the geochemical and geophysical monitoring activities, and come to $4.6 million.

Planning of the pilot project could start in 2004 and construction will occur over the next two years from 2005-2006. Execution of the project would start in earnest in 2006, with continuous CO_2

injection for 2 years, ending in 2008. The estimated budget for the pilot project, including monitoring and verification is $ 18 million. If the pilot is a technical success after two years, a commercial demonstration would be considered.

Monitoring Activity	Unit Cost	Total Cost
Timelapse 4D seismic (5 surveys)	$200k	$1,000k
Vertical seismic profile (3 surveys)	$100k	$300k
Passive seismic (continuous)	$100k	$100k
Cross well seismic (if opportunity arises)	$100k	$100k
Tiltmeters (continuous)	$300k	$300k
Production well geochemistry (10 surveys)	$15K	$150k
Aquifer geochemistry (pressure & chem.)	$100k	$100k
Water well geochemistry (3 surveys)	$50k	$150k
Soil gas geochemistry (3 surveys)	$50k	$150k
Baseline geology	$10k	$10k
Observation wells (3)	$700k	$2,100k
Logs (3 surveys)	$50k	$150k
Grand Total Monitoring Costs		**$4,590k**

A More Detailed Budget for the HGCS Commercial Demo

If the pilot project indeed goes to the next phase, it could be a commercial demonstration project involving 4 patterns (13 wells), at a well spacing of 160 acres (four time larger spacing than the pilot). Assuming the reservoir is depleted from 8 years of primary production, some preliminary reservoir simulations based on a hypothetical scenario of a 22 year CO_2 flood with CO_2 injection at 52t/day/injector well have been made in order to evaluate the cost of the demonstration. The reservoir properties used to make the simulation were a porosity of 0.16, an absolute permeability of 25 md, an initial temperature of 63^{o}C, an initial reservoir pressure of 15 MPa, a depleted reservoir pressure of 3.8 MPa prior to flooding, initial saturations of water = 0.6 and of oil = 0.4, and an original-oil-in-place of 744,492 m^3 (4,682,854 barrels) (160 acres). This corresponds to an oil reservoir slightly deeper than in the Industrial Heartlands area. However, considering the other uncertainties involved in the calculation of the economics, this difference is not critical.

Twenty-two year CO_2 Flood	**4 x 160 acres**
Oil recovered (10^3 barrels)	6,066
Recovery of Oil-in-place	31.3 %
CO_2 utilization rate (MCF/bbl):	
- gross	5.42
- recycle	4.17
- net	1.25
Capital Investment	**$ 15.5 million**
Supply Cost: ($ /bbl)	
- Oil operating cost	1.82
- CO_2 related cost	4.64
- water treatment cost	0.02
- other operating and capital cost	6.95
- total	**$13.43/barrel**

Based on reservoir simulations, oil production rate, cumulative oil production, cumulative water production and cumulative CO_2 injection and production, capital investment are estimated at $ 15.5 million, assuming that existing wells and surface facilities from the pilot will be utilized and expanded if feasible (as tabled above). It is assumed that although the CO_2 was donated for the pilot, it must be purchased for the commercial demonstration. It is further assumed that the CO_2 is available to be delivered on site at a cost of $ 28.5 /t. The operating costs of the demonstration are approximately $ 3 million/year which results in a supply cost of $13.43 per barrel of oil produced or a total cost of the project of $81 million over its 22 years of operation at a 12% rate of return. However this project averages only 5.4mcf/barrel gross CO_2 and 1.3mcf/barrel net CO_2 injected compared to more typical figures of 10 gross and 5 net mcf CO_2 injected per barrel of oil produced. Due to the optimal lower than average CO_2 utilization rate and a currently high market price of $30/barrel oil, the project would realize $180 million gross income accounting for a profit of approximately $100 million. Also due to the low utilization rates, only 400,000 tonnes of CO_2 is stored out of 1,600,000 tonnes injected over the 22 years. No credit was given for the CO_2 stored.

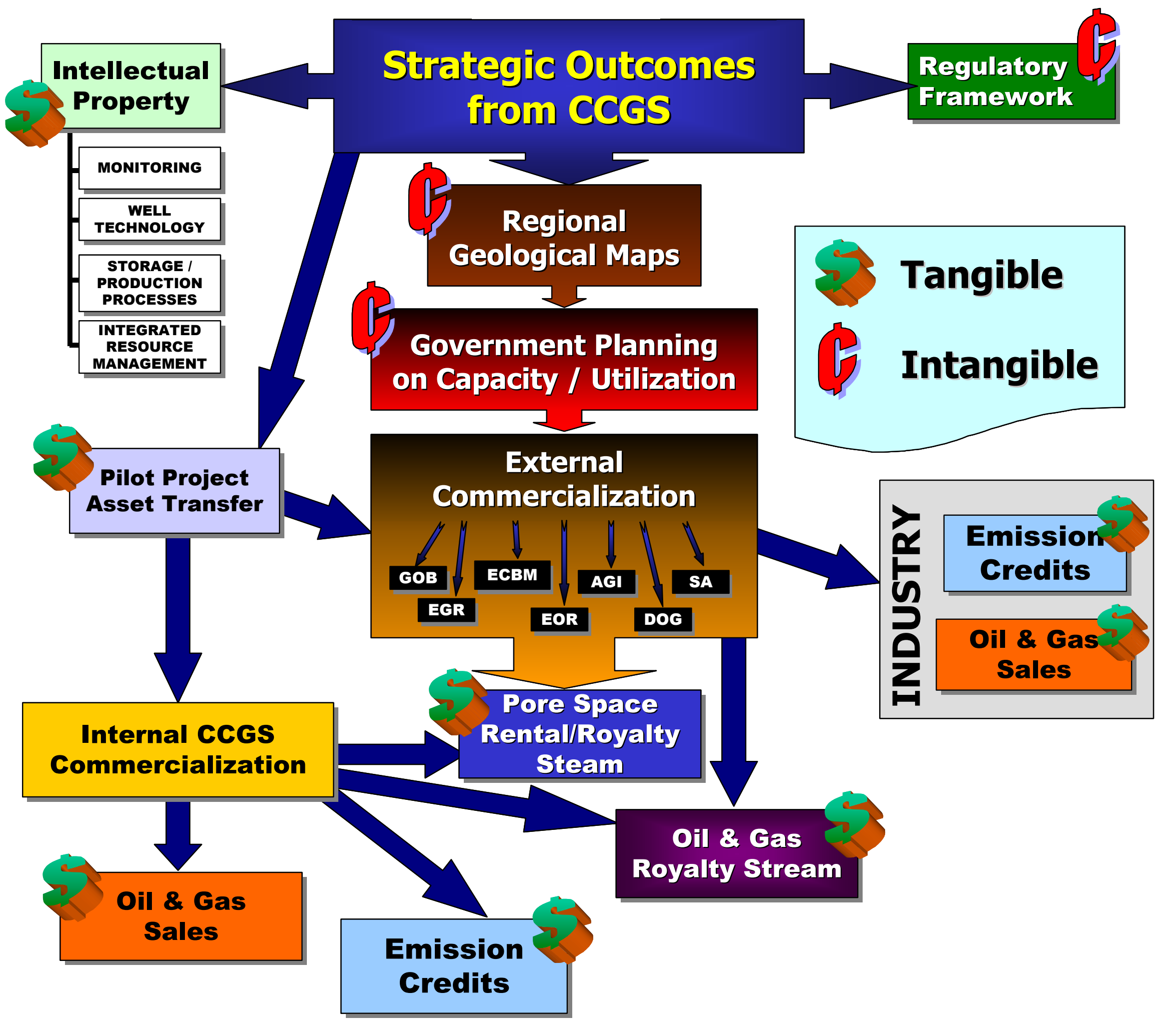

Figure H.1 Revenue streams from CANiSTORE

This example points out the leverage that a program such as CANiSTORE can deliver. Although the cost of the program seems high in the short term, any commercial projects which evolve from it, can potentially offset costs in the long term through royalty streams and credits as already suggested in Figure H.1.