Summary of Canadian CO_2 Capture and Storage Technology Initiatives

Promoting Zero Emissions Technologies ...

There has been interest in the implementation of components of CO_2 capture, storage and utilization technologies (Zero Emissions Technologies) for some time in Canada. At the first conference organized by the IEA Greenhouse Gas R&D Programme on CO_2 capture and storage in Oxford, UK in 1993, Canadians gave papers on, among other topics, **amine capture**, **membrane separation** and **calcium carbonate formation**. Canadian activities prior to that time included pilot projects on CO_2 enhanced oil recovery. A western Canadian information network was also in existence, bringing together interested players and exchanging information on CO_2 capture, storage and utilization technologies. Congruent with the above interests, Canada was one of twelve IEA member countries that founded the IEA Greenhouse Gas R&D Programme in 1991. A high national commitment to this initiative resulted in Canada playing a leadership role since 1995 as Chair of the Executive Committee of the IEA Greenhouse Gas R&D Programme.
Since negotiation of the 1997 Kyoto Protocol, Canada has been working towards its ratification. **The target is to reduce annual greenhouse gas emissions to a level of minus 6 % by 2008-2012 relative to the 1990 level, which is estimated to have been the equivalent of 601 megatonnes (Mt) of CO_2.**

Some current Canadian initiatives in CO_2 Capture and Storage include:

- Technology development and cost reduction of CO_2 capture using oxy-fuel combustion and amine separation;
- Gasification of coal for electricity production and CO2 capture;
- Study of acid gas (CO_2 and H_2S) underground injection;
- Monitoring of CO_2 storage in enhanced oil recovery;
- Enhancement of methane recovery through monitoring of CO_2 injected into deep coal beds;
- Storage capacity assessments of Canadian sedimentary basins, coal seams and oil and gas reservoirs.

Many of the projects underway involve public and private sector partnerships, international collaboration, with several of the projects being also led by the private sector.

Acid Gas Injection in Alberta and British Columbia, Canada

At the end of 2003 there were 41 operations in Alberta and British Columbia where acid gas was re-injected into depleted oil and gas reservoirs and deep saline aquifers. The composition of the injected gas varies from 2% H_2S and 95% CO_2, and 83% H_2S and 14% CO_2. These acid gas injection operations in western Canada represent an analogue for geological sequestration of CO_2. Thus, the study of the acid gas injection operations provides the opportunity to learn about the safety of these operations and about the fate of the injected gases, and represents a unique opportunity to investigate the feasibility of CO_2 geological storage.

The Alberta Geological Survey (AGS) of the Alberta Energy and Utilities Board (EUB), and the Alberta Research Council (ARC), are jointly carrying out a multi-year project to characterize these acid-gas injection operations by collecting all the information submitted by operators to regulatory agencies, and from additional sources. A comprehensive hydro-geological characterization by operation clusters is being performed, with the objective of selecting a monitoring site for better understanding the fate of the injected acid gas. In addition, one site underwent a comprehensive due diligence to establish the viability and importance of this technology for creating greenhouse gas emission credits when a trading market is firmly established.

Duration: December 2001 to March 2005

Funding Level & Funders: $ 205,000 for Phases I and II, and $530,000 for Phase III from Canadian federal and provincial governments and government agencies, the IEA Greenhouse Gas R&D Programme, and industrial partners.

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Advancement of a Multi-Tiered Online Auction Website Designed to Foster the Development of a Sustainable Carbon Dioxide (CO_2) Market

the CO_2 hub was designed to foster the development of a sustainable carbon dioxide (CO_2) market.

'the CO_2 hub' is a unique, multi-tiered online trading platform that seamlessly facilitates transactions between buyers and sellers of CO_2 and emission reduction units. This auction website was designed to foster and support the utilization of CO_2 for enhanced petroleum recovery, sequestration of CO_2 and the trading of CO_2 emissions credits.

In addition, stakeholders can seek critical auxiliary services (purification, compression, storage and transportation) and benefit from an accurate documentation tracking system to monitor volumes bought and sold in support of potential emissions credits. The Analyst's Hub facilitates stakeholder awareness of the opportunities and issues associated with the CO_2 supply chain. *the CO_2 hub* is intended to foster price discovery and 'best economics' for all related stakeholders.

Within CANiSTORE, *the CO_2 hub* would serve well as the facilitation infrastructure, helping to link potential projects and partners, monitor the CO_2 supplies delivered to the pilots and promote the development of the necessary service infrastructure required for project commercialization.

Private/public investment is sought to further develop *the CO_2 hub* to meet the particular needs of Canadian stakeholders (industry, government, research) as this market evolves.

Duration: 3 years

Funding Level and Funders: $1,000,000 ($500,000 'in-kind contribution' from *the CO_2 hub*; funding partners sought for the remainder)

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Canadian Clean Power Coalition

An association of seven Canadian utilities and coal producers, the International Energy Agency and the US Electric Power Research Institute, the Coalition proposes a program focused on "securing a future for coal-fired electricity generation." The proposal provides for the development, construction and operation of a full-scale demonstration project by 2012, which will remove GHG, and other emissions of concern from a greenfield coal fired power facility.

The Coalition's proposal is expected to cost approximately $1billion Canadian. Phase I of the project (conceptual engineering and feasibility studies) began in September 2001, with secure industrial funding and signed agreements with the provinces of Alberta and Nova Scotia, and commitments from the federal government and the province of Saskatchewan. Phase I was completed in early 2004 with the assessment of the technologies to be used in the demonstration. Phase II (technology gap analysis and business plan development) commenced in spring 2004 and is expected to be complete at the end of 2005. Phase III (detailed engineering and construction) is expected to commence in 2006.

Duration: Phase I: September 2001 to early 2004, Phase II scheduled for completion 2005, Phase III in 2012.

Funding Level & Funders (Phase I): Industrial Participants (funding in place) $2.15 million, Province of Alberta (funding in place) $0.555 million, Province of Saskatchewan $0.333 million, Government of Canada $1.67 million, Nova Scotia Department of Natural Resources (in place) $15,000 plus $15,000 in kind.

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CANMET CO_2 Consortium: Development of Oxy-fuel combustion technology for CO2 capture and storage.

Currently in Phase 7 of a work program focused on O2/ CO_2 recycle combustion strategies for retrofit and new pulverized coal fired power plants. CANMET is the primary performer of the work. The research program is aimed at improved understanding of oxy-fuel combustion, heat transfer and pollutant formation behaviour and validation of novel burner concepts using a purpose built oxy-fuel combustion pilot plant rated at a 0.3 MW input. Integrated CO_2 purification and multi-pollutant capture mechanisms are also being studied in a condensing heat recovery and scrubbing environment using technology supplied by Babcock and Wicox, USA. Boiler simulation tools are being developed for use in a HYSYS working environment. Outputs of the program are confidential to partners, however several papers have been released in the public domain.

Duration: Program started in 1994, currently in Phase 7

Funding Level and Funders: Currently receives approximately $1 million Canadian/year and is supported by the IEA Greenhouse Gas R&D Programme, Canadian federal government, Alberta government, US Department of Energy, several Canadian utilities, Babcock & Wilcox, USA and in the past by TransAlta, EPCOR, Nova Scotia Power and Air Liquide.

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Cassiar Tailings Mineralogy, Toxicity and Suitability for CO2 Sequestration, (an evaluation of)

The project will evaluate the efficacy of natural carbonation reaction involving atmospheric CO_2 and serpentine mine tailings at Cassiar as a potential natural analogue for commercial CO_2 sequestration. It will also determine the amphibole content of the tailings. Fibrous amphibole can cause asbestosis. Even small quantities in the tailings would complicate handling of the tailings, detrimental to its use in commercial CO_2 sequestration. It is a collaborative project between the University of British Columbia and the British Columbia Ministry of Energy and Mines.

This academic study has a field and laboratory component. This project will examine, sample, and analyze the tailings pile at Cassiar to determine if carbonation is proceeding in the natural environment, and document the source of crystallographically bound CO_2.

Depending on future funding and industry interests, this preliminary study may lead to demonstration or commercial research project(s).

Complete consumption of the tailings pile would sequester approximately 8 million tonnes of CO2, but the technological requirements of conversion are not yet known.

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Background information is also available at UBC EOS website:
http://www.eos.ubc.ca/research/dipple/UBC_Carbonation/index.htm

Closed Gas Turbine Cycle Project

Performance evaluation of various closed gas turbine and fuel cell based cycles utilizing oxy-fuel combustion to produce power and capture CO_2. Work program includes simulation activities and primary research at two Canadian universities. The work at Carleton University on the Raven Zero-Emission Gas Turbine, is focused on the design and construction of a 70 KWe natural gas fired generator set using pure oxygen combustion with CO_2 re-circulation. Design parameters and concepts learned from the pilot scale work will be used to model the operations of a 100 MWe industrial scale facility. Work is underway at the University of Waterloo to develop a simulation of solid oxide fuel cell (SOFC), which can be integrated with a gas turbine bottoming cycle.

Duration: April 2002 – March 2006

Funding Level and Funders: Currently $850,000 Canadian over 5 years from Climate Change Action Plan (CCAP) Program.

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CO_2 Sequestration in British Columbia

The project incorporates a review of CO_2 sequestration and storage technologies. Preliminary review of potential CO_2 sinks and of major point sources, essential for any informed decision-making regarding CO_2-storage in BC, is also part of this study. Characterization of ultramafic rocks for mineral carbonation is currently underway. It is a collaborative project between British Columbia Ministry of Energy and Mines and the University of Victoria. Depending on possible future collaboration with NRCan, this scooping study may lead to demonstration or commercial research project(s). The study has a field and laboratory component. Part of the laboratory work related to mineral carbonation will be carried out in collaboration with the Albany Research Center (USA). The study fills gaps in the existing data, which is required to do informed decision-making about CO2 sequestration in BC and possibly elsewhere in Canada. The cost and storage capacity could be incorporated into follow-up studies.

Duration: Sept 2002 – Sept 2004

Funding Level & Funders: British Columbia Ministry of Energy and Mines funds one student at University of Victoria. Funding for current fiscal year 2002/2003 is CAD 30,000.

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Background information is also available at Ministry of Energy and Mines Oil and Gas Website.
http://www.em.gov.bc.ca/subwebs/oilandgas/resource/carbon.htm

The potential for CO2 Sequestration in British Columbia Coal Seams

This project collects coal samples from a number of coalfields in British Columbia and analyzes them for CO_2 isotherm. For each sample, CO_2 adsorption on coal, influence of coal rank and petrography on CO_2 adsorption, and influence of temperature on CO_2 adsorption are studied. The final report is an initial study of the CO2 sequestration potential for coals in British Columbia.

The study includes sampling and CO2 isotherm analysis on samples collected. Results are documented in a research paper.

The results indicate that CO_2 is strongly adsorbed onto coal and that the adsorption capacity changes with rank. However the adsorption behaviour of CO_2 as rank and coal petrography change is different from that of CH_4. The mole ratio of CO_2/CH_4 adsorption varies from over 10 for low rank coals to under 2 for medium and high rank coals. CO_2 adsorption is moderately high for low rank coals, decreases for medium rank coals and then increases substantially for high rank coals.

The interaction of adsorption and selectivity of CO_2 and CH_4 means that for maximum CO_2 sequestration with minimum production of CH_4 one should use lignite. It is important to note that sequestration of CO_2 without collection of the released CH_4 may result in a net increase in the emission of green house gases over time. For maximum sequestration of CO_2 with maximum production of CH_4 during enhanced CBM recovery one should use a high rank coal.

Sequestration and enhanced CBM recovery only apply to a depth window defined by the range of pressure and temperature conditions over which CO_2 is a gas. It is important to project a depth tract in to the phase diagram based on actual temperature and pressure gradients existing in a coal basin. This will indicate the maximum depth for sequestration, which varies based on combinations of geothermal and pressure gradients, and is generally in the range of 500 to 900 metres.

There are a number of practical constraints on CO_2 sequestration. Often a pure stream of CO_2 is not available and the adsorption behaviour of a mixture of CO_2 and N_2 is not clearly understood. The mixture may influence the shape of the pure CO_2 phase diagram. Injection of CO_2 causes coal to swell in part because of adsorption and in part because CO_2 is dissolved in the coal structure. This may decrease permeability and prevent further injection.

The best application of CO_2 sequestration may be in conjunction with CBM extraction and use. In this case the coal volume is adequate to sequester the CO_2 produced by burning the CH_4.

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The report can be obtained at: http://www.em.gov.bc.ca/subwebs/oilandgas/resource/carbon.htm

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

Utilization of the many oil and gas well intersections of deep coal seams to determine the distribution, thickness and depth of deep coals; to determine reservoir properties including pressure and temperature and through experimentally derived CO_2 adsorption isotherms, to determine the in place storage capacity expressed as megatonnes/square kilometer.

Duration: This work has continued intermittently since 1997 as funding becomes available from groups outside of the Geological Survey of Canada. Ongoing work, to be completed in 2003, is funded by the Climate Change Action Plan.

Funding Level and Funders: Funding is $275,000 Canadian for fiscal year 2002-2003. A separate project has been negotiated to assess the CO_2 storage capacity in Nova Scotia with the Canadian Clean Power Coalition.

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CO2 Storage by Mineral Carbonation Reactions: Kinetic and Mechanical Insight from Natural Analogs

This project examines geologic analogs to mineral carbonation reactions to assess the feasibility of permanently storing CO2 in subsurface magnesium silicate rocks. Project outcomes include establishing the mechanical and hydrologic consequences of mineral carbonation reactions, documenting reaction paths and mechanisms, and constraining the timing and rates of carbonation reaction in bedrock CO2 alteration systems. Field site is Atlin, northwest B.C. Laboratory work undertaken at the University of British Columbia.

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Background information is also available at UBC EOS website:
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Emission-Free Coal and Carbon Energy Technology with Integrated CO_2 Capture

ZECA Corporation (ZECA) is a private carbon management venture that embodies a U.S.-Canadian collaboration that succeeded the Zero Emission Coal Alliance (The Alliance) in 2001. ZECA's shareholders include utility, mining, mining manufacturing and coal interests. ZECA is currently managed from Calgary, Alberta.

ZECA is the exclusive world licensee (from the University of California) of patented **Emission-Free Coal and Carbon Energy Technology (E-F Technology)** that was developed at Los Alamos National Laboratory (LANL) and Louisiana State University. This technology, which is currently the main focus of ZECA's work, uses hydrogasification and calcium oxide reforming to produce hydrogen from coal, petroleum coke, bitumen, heavy oil, biomass etc. while simultaneously producing 'pure' carbon dioxide for sequestration The hydrogen may be used for upgrading (oilsands), production of electricity or off-site sales. Initially hydrogen fueled turbines may be used for generating electricity but, ultimately, development of a robust, sulphur tolerant, solid oxide fuel cell will be important to achieve 'water-free', zero emission electricity production using this technology (recent advances have identified the materials to achieve this goal).

The **E-F Technology** makes hydrogen before it makes electricity (not from electricity). As such, the advantage of the hydrogasification concept is that will be an inexpensive source of hydrogen and will automatically provide 100% CO_2 capture at no cost and at high pressure, ready for sequestration. The CO_2 can be sequestered in any safe manner. Initially it can be used for Enhanced Oil Recovery (EOR), Enhanced Coal Bed Methane (ECBM) production or simply injected into deep saline reservoirs. ZECA's view is that, over time, it will be increasingly practical to sequester the CO_2 as mineral carbonate by reacting it with magnesium silicates such as serpentinite or dunite (olivine) to form magnesium carbonate and silica, which are then returned to the serpentine mine. Magnesium carbonate is benign and thermodynamically stable, thus guaranteeing permanent and safe sequestration of the CO_2. The capacity of worldwide magnesium silicate deposits is more than sufficient to handle the captured CO_2 emissions from all the world's coal burning facilities.

ZECA was established after The Alliance had received a comprehensive report from Nexant, a Bechtel company, indicating that the scientific concepts of the **E-F Technology** were technically viable and that it had the potential to produce electricity from coal with very high efficiencies (70% HHV) at prices comparable to new coal plants without carbon management. Since that time Nexant has also completed a screening study that indicates that **E-F Technology** would be a competitive source of hydrogen for oil sands upgrading at natural gas prices of US$2.70 or more. Recent research has confirmed that anode materials that are completely impervious to sulphur at 1000°C are available, that complete removal of mercury from aqueous slipstreams is possible and that catalyst requirements may not be as significant as initially projected. Technical and business plans to design, construct and operate a pilot plant within five years are currently being developed.

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Visit the ZECA Corporation Website for more details: http://www.zeca.org/

http://www.zeca.org/overview_docs.html

Enhanced Coalbed Methane and CO_2 Storage Piloting in Qinshui Basin, Shanxi Province, China

China is rich in both coal and coalbed methane resources. China is the world's largest coal producer and consumer, and one of the largest source of greenhouse gases emissions. Consequently, the Alberta Research Council, Sproule International Ltd., the Computer Modelling Group, Computalog, CalFrac, SNC Lavalin, and Porteous Engineering (the Canadian ECBM Consortium), that together with China United Coalbed Methane Company Ltd., will promote environmentally sustainable development in China through the transfer of Canadian CBM/CO_2 storage technology to effectively exploit CBM while storing CO_2 in unmineable deep coal beds.

A single well micro-pilot test was carried out in the anthracitic coal's of the Qinshui Basin from late 2003 until mid 2004. The data and information collected is still under analysis, but the results are very promising, and hopefully will lead to the successful implementation of a field-pilot.

Duration: 2002 - 2005

Funding Level and Funders: Funding is $10,000,000, of which 5,000,000 come from the Canadian International Development Agency (CIDA) under the Canadian Climate Change development Fund (CCCDF), 5,000,000 come from China Ministry of Commerce through China Coalbed Methane Company..

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Enhanced Coalbed Methane Recovery for Zero Greenhouse Gas Emissions

Supported by the IEA Greenhouse Gas R&D Programme and led by the Alberta Research Council, this Canadian project is looking at the commercial viability of coal bed methane (CBM) in Alberta through enhancement of CBM recovery factors and production rates in low permeability CBM reservoirs by injection of carbon dioxide-rich waste streams; and reducing greenhouse gas emissions by subsurface injection (and storage) of carbon dioxide into coal beds with added value from production of CBM. Phase I of the Canadian project was the initial assessment and feasibility of injecting pure CO_2 into deep Mannville coals. Phase II was the design and implementation of a micro-pilot test for injection of pure CO_2 in an existing CBM well located at Fenn-Big Valley in Alberta following Amoco Production Company procedures. Phase III was the assessment of reservoir response to different compositions of injected flue gases and the design and implementation of a multi-well pilot project. Phase IV is the matching of novel combustion and separation technologies to produce a CO_2 waste stream with CBM reservoirs to carry out additional multi-well ECBM pilot tests. To date, all testing undertaken in Phases I-III has been successful and the economics of the process is being assessed.

It is expected that the final results will show gas producers the best way to enhance production from low permeability CBM wells. On the other hand, reducing greenhouse gas emissions is a priority to the utilities and is addressed. Cost curves will be generated to assess the price per tonne of CO_2 stored in coal reservoirs based on a wellhead price of natural gas and composition of flue gas injected.

Funding Level and Funders: To date more than $4 million Canadian has been expended. Current partners include IEA Greenhouse Gas R&D Programme, Environment Canada, Canadian Climate Change Action Plan, Geological Survey of Canada, Alberta Innovation and Science, Alberta Geological Survey, Saskatchewan Energy and Mines, US Department of Energy, UK Department of Trade and Industry, Netherlands TNO, Japan Coal, Australian CSIRO, Gas Technology Institute, Suncor Energy, BP, Burlington Resources, Conoco Canada, EnCana Corporation, MGV Energy Inc., Exxon Mobil Canada, Husky Energy, PetroCanada, TransCanada Pipelines, EPCOR Utilities, TransAlta Utilities, Air Liquide, Sproule International, Tesseract, University of Alberta, University of British Columbia and BJ Services Canada.

Duration: 1997 to 2005.

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Fixation of Greenhouse Gases in Mine Residues

This academic project will examine the feasibility of storing atmospheric CO2 in historical and active mine residues. Research conducted at the University of British Columbia and mine sites in B.C., the Yukon and the N.W.T.

The study involves fieldwork and sampling, laboratory and experimental analysis, and geochemical modelling. It will examine the rates and processes of natural fixation of atmospheric CO2 in a variety of mine residues.. Depending on future funding and industry interests, this preliminary study may lead to demonstration or commercial research project(s).

Storage capacity is dictated by the size of mine residues. Average size mining operations could sequester hundreds of thousands to millions of tonnes of CO2.

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Background information is also available at UBC EOS website:
http://www.eos.ubc.ca/research/dipple/UBC_Carbonation/index.htm

Geologic sequestration of CO_2 and simultaneous CO_2 sequestration / CH4 production from natural gas hydrate reservoirs

While laboratory and field data are lacking, in theory two options are available: 1) geologic sequestration of CO_2 in conventional geologic reservoirs, and 2) co-production of methane during sequestration of CO_2 in existing natural gas hydrate reservoirs.

This research project will assess the feasibility of geologic sequestration of CO_2 as gas hydrate and the possibility of coincident CO_2 sequestration/ CH4 production from natural gas hydrate reservoirs such as those occurring offshore of Canada's coasts, the Great Lakes, or in the Arctic. A variety of natural gases form natural gas hydrates (crystalline substances composed of water and gas), which are known to occur in significant volumes in offshore sediments and beneath terrestrial permafrost. Carbon dioxide can exist as stable gas in a variety of geologic environments characterized by moderate pressure and relatively cold temperatures. A unique feature of gas hydrate is the capacity to concentrate gases within a crystalline matrix, such that a single unit volume of hydrate may contain over 160 volumes of free gas equivalent at atmospheric pressures. Given the intrinsic efficiency of CO_2 storage within the clathrate structure, it can be concluded that a huge sequestration potential exists in close proximity to point source emissions in western and eastern Canada. While laboratory and field data are lacking, in theory two options are available: 1) geologic sequestration of CO_2 in conventional geologic reservoirs, and 2) co-production of methane during sequestration of CO_2 in existing natural gas hydrate reservoirs.

Theory, and limited laboratory data suggest that excess CO_2, when introduced into a methane hydrate reservoir, may displace entrained methane in favour of the formation of stable CO_2 hydrate. Areas offshore of Canada's west coast, and a number of onshore Arctic locations are known to contain some of the most concentrated methane hydrate deposits in the world. This raises the attractive possibility of coincident production of methane during sequestration of CO_2. Research in this area is in its infancy.

Project Objectives:

1. Conduct a program of fundamental laboratory research to establish the porous media controls on CO_2 hydrate formation in geologic media, and to investigate the thermodynamic conditions favouring the displacement of CH4 from methane hydrate by injection of CO_2.
2. In conjunction with drilling of the 2002 Mallik International Gas Hydrate Production Research Well, conduct field investigations of the physical, geothermal, and geochemical characteristics of an existing gas hydrate-bearing reservoir.
3. Using archived geologic data, identify and characterize a suite of candidate marine, lacustrine and Arctic reservoirs suitable for geologic sequestration of CO_2.
4. Assess the feasibility of geolologic sequestration of CO_2 as gas hydrate, with respect to both terrestrial and marine reservoirs in Canada.
5. Evaluate the feasibility of co-production of methane gas in conjunction with CO_2 injection in existing natural gas hydrate reservoirs.

Duration: 4 years

Funding Level & Funders: Climate Change Action Plan, $307,000 Canadian for 4 years.

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Hollow Fibre Membranes for CO_2 Separation

The Alberta Research Council is pursuing new ways to improve the efficiency of CO_2 separation from synthetic flue gas using micro-porous hollow fiber technology. Conventional technology for separation of CO_2 from gas streams involves contacting of gas with aqueous-amine solution in a tower. The amine selectively absorbs the CO_2, and then is transferred to another unit where it is heated, and the CO_2 released and separated. The amine is cooled, returned to the gas contact tower, and the cycle is repeated. Some disadvantages to using this technique are flooding, unloading, foaming and most important, corrosion problems.

Using micro porous hollow fibers as the absorber in a packed tower is a relatively new concept and has the potential to offer significant advantages over the conventional packed bed absorber. The following advantages are provided by micro porous hollow fiber modules: 1) High gas/liquid contact area due to high packing density provided by hollow fiber membrane. 2) Gas and liquid flow rates may vary in a wide range without causing flooding problems. 3) Hollow fiber membrane contactors may be operated in any orientation to suit overall plant layout and the process capacity because of its module design. 4) Low operation pressure. 5) In addition, inorganic-salts based solvents also offer the advantages such as, low cost solvent, no solvent oxidation and degradation, as well as lower desorption energy. Among all the advantages, the low operational pressure and no solvent oxidation and degradation would make it more suitable to the application of the CO_2 capture from flue gas. The Alberta Research Council is focusing on improvements in areas #1, #4 and #5 from bench to module scale.

Duration: 1999 – 2006

Funding Level and Funders: $400,000
Alberta Research Council Inc.
Natural Resources Canada.
AERI (anticipated)
Industry Partner (anticipated)

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IEA GHG Weyburn CO_2 Monitoring and Storage Project

The IEA GHG Weyburn Monitoring and Storage Project is an international research and demonstration project intended to establish the degree of security with which greenhouse gases, particularly CO_2 can be sequestered in geological formations during large scale, commercial, EOR operations. This will be accomplished through the scientific mapping of the movement of CO_2 in the reservoir, and technical prediction of the future long-term storage and migration characteristics of the CO_2. It builds upon a $1.5 billion commercial, world-class, CO_2-EOR operation at Weyburn, Saskatchewan, near the US border with North Dakota. The ultimate deliverable is a credible assessment of the permanent containment of injected CO_2 as determined by long-term predictive simulations and formal risk analysis techniques. Results will help answer questions regulatory bodies have as to the security of large volume CO_2 sequestration/storage not only in the Williston Basin, but also in other basins where CO_2 storage is contemplated.

Duration: Phase I: September 2000 – July 2004; Phase II: July 2004 – July 2008

Funding Level & Funders: Phase I of the project had a budget of $42 million. Phase II is expected to have a similar level of funding. Funding sources: Natural Resources Canada, US Department of Energy, Saskatchewan Industry and Resources, Alberta Energy Research Institute, European Community, IEA GHG R&D Programme, EnCana Corporation, SaskPower, Nexen Canada, Total, Chevron Texaco, BP America, Dakota Gasification Co., TransAlta Utilities Corp., Engineering Advancement Association of Japan (ENAA)

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www.co2sequestration.info
www.ptrc.ca (under development)

Integrated Economic Model for CO_2 Capture and Storage

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 from fossil energy through the 21st century. 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 royalties). Alberta Reseach Council, Energy Navigator, SNC Lavalin, and the Computer Modelling Group are developing such a tool. The integrated model will be able to handle the four distinct businesses – CO_2 capture, CO_2 transport, injection/energy production and CO_2 storage/credits. It will be able to evaluate individual project proposals and groups of projects (for province-wide impacts). The fiscal regime treatment and evaluation will depend on proper 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, and a friendly user interface with tables and graphics outputs

Duration: 2004 - 2006

Funding Level and Funders: $500,000
Energy Navigator Inc. (in-kind contribution - software development)
SNC Lavalin Inc. (in-kind contribution – process engineering)
AERI (anticipated)

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International Test Centre for Carbon Dioxide Capture (ITC): Regina, Saskatchewan, Canada

The International Test Centre (ITC) is developing post-combustion capture technologies that will reduce the cost and energy penalty of CO2 production. This work will pave the way for the development of new storage and industrial use opportunities.

The Centre builds on the existing internationally recognised expertise at the University of Regina. The capital component of the ITC consists of two components: a pre-commercial demonstration facility attached to a coal-fired electrical generating station and a technology development unit with extensive analytic and research capacity at the University site.

These include three pilot plant units for testing high efficiency gas treating systems which consists of different sizes of absorption and regeneration towers packed with a variety of high performance packings. We have also built and/or acquired a number of pieces of research units for solvent absorption capacity testing, solvent stability and corrosion studies, and gas/liquid diffusivity determination.

Duration: 2002 – on going

Funding Partners: SaskPower, Fluor Canada Ltd., Nexen Canada Ltd., Luscar Ltd., TransAlta Utilities Corp., Encana, EPCOR Utilities Inc., Petroleo Brasileiro S.A. (Brazil), Alberta Science and Research Authority, Saskatchewan Energy & Mines, IEA Greenhouse Gas R&D Programme. We are still open for more members.

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Mineral carbonation in chrysotile mining waste: biological and chemical processes

This small-scale fundamental research project investigates carbon sequestration in chrysotile mining and milling residues, in Eastern Townships. Biologically mediated spontaneous carbonation, autoclave experiments of mineral carbonation using real waste materials and various pre-treatment approaches, by-product metal recovery and cost analysis. There are 700 Mt of CO2 storage capacity in mine and mill residues in Eastern Townships.

Duration: 2003 to 2006

Funding Level & Funders: Hydro-Quebec Production, Bureau des changements climatiques (Environnement Québec), Lab-Chrysotile, NSERC (application to be submitted)

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Monitoring of Alberta's 4 Experimental EOR Pilots

The monitoring and verification of CO_2 storage is critically important because the public must be assured that the gases have been removed permanently from the atmosphere. CO_2 storage is attractive for Canada since a large percentage of our CO_2 emissions come from fixed-point sources such as power plants and hydrocarbon 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 neighboring aquifers through a variety of mechanisms.

Monitoring is one critical area for validation of geological storage. An Alberta-based multidisciplinary team has been formed by the Alberta Research Council, the Alberta Geological Survey, the University of Alberta and the University of Calgary to advance monitoring technologies in this area. Tag-on opportunities to oil recovery projects such as EOR operations allow these monitoring studies to proceed from pilots to existing commercial operations where the storage of CO_2 is viewed as "added value" for the future, after a viable emission trading system has been put in place. The Alberta CO_2 Royalty Credit Program has approved four EOR pilot sites in Alberta, and represents an opportunity to test monitoring technology at the pilot scale with a potential opportunity to become commercial.

The four pilot sites have been ranked according to the potential that they have to provide a better knowledge and understanding of the EOR-CO2 storage processes. Likewise, a framework for the monitoring program has been put in place, where integrated technologies such as seismic imaging, geochemical analysis, and hydrogeology can document the motion of the injected gases and detect leakage from the storage horizon. The monitoring program will start in late 2004.

Duration: 5 years

Funding Level and Funders: $2,000,000 (anticipated)

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Oxy-Fuel Field Demonstration Project

This project aims to design, build and test the world's first industrial scale gas fired oxy-fuel demonstration system for CO_2 capture. CANMET Energy Technology Centre - Ottawa will be responsible for optimizing the overall process and scaling up a proprietary oxy-fuel burner concept. The system will incorporate a steam generator and power generation unit.The unit will aim to produce a high CO2 purity product stream which is suitable for compression and injection into a variety of geological storage media.

Duration: 2001 – March 2006

Funding Level and Funders: Seed funding of 1.38 million dollars Canadian over 5 years from the Climate Change Action Plan, currently seeking industrial partners.

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PTRC Studies on CO_2 Utilization and Extraction

Researchers at the Petroleum Technology Research Centre (Regina, Sask.) are developing technologies to promote the storage of carbon dioxide (pure or extracted from waste flue gas) through its use as an enhanced oil recovery (EOR) agent. Prime objectives are: to improve the performance and economics of CO_2 floods; to extend the applicability of CO_2 injection from light/medium oil reservoirs (such as Weyburn); to fields containing heavier oils to expand the potential sources of CO_2. This project will address several areas where technology gaps exist, such as: application of cyclic gas injection (huff-n-puff) to waterflooded oil reservoirs; immiscible CO_2/flue gas injection in thin heavy oil reservoirs (a majority of Saskatchewan's reservoirs); optimization of gels and gel placement techniques to control CO_2 conformance to improve sweep efficiency and thus expand reservoir storage volume; identification of mechanisms of CO_2 oil recovery enhancement and sequestration formation of clathrate hydrates to isolate CO_2 from flue gas.

Duration: March 2002 – April 2007

Funding Level & Funders: Industry participants, Petroleum Technology Research Centre, Saskatchewan Research. The program has a budget of approximately $500,000 Canadian.

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www.ptrc.ca (under development—includes links to researchers)
www.src.sk.ca (under development—includes links to researchers)

Sequestration of Carbon Dioxide in Oil and Gas Reservoirs in Western Canada

Provincial reserves databases in British Columbia, Alberta, Saskatchewan and Manitoba record ~37,000 gas reservoirs and ~10,500 oil pools, of which the great majority are in Alberta. The theoretical and effective capacities for CO_2 sequestration in these reservoirs have been estimated using methodology developed at the Alberta Geological Survey. Results to date indicate that the effective CO_2-sequestration capacity in gas reservoirs is ~8.5 Gt CO_2. In contrast, the sequestration capacity in oil pools at depletion is only 450 Mt CO_2. Of the more than 10,500 oil pools, 4,748 reservoirs were identified as suitable for CO_2-flood EOR. Estimates of the incremental CO_2-sequestration capacity in these reservoirs at CO_2 50% hydrocarbon pore volume (HCPV) of injected CO_2 indicate that an additional 640 Mt CO_2, would be sequestered through CO_2-flood EOR. However, the great majority of the oil and gas pools in western Canada have small CO_2-sequestration capacity. Only 771 gas reservoirs and 98 oil reservoirs have an estimated CO_2 sequestration capacity greater than 1 Mt CO_2 each, but their cumulative capacity is 3.2 Gt CO_2 for gas reservoirs and 560 Mt CO_2 in oil reservoirs.

The methodology for screening oil reservoirs for CO_2 flood enhanced oil recovery (EOR) and for estimating their CO_2 sequestration capacity, and for estimating the effect of underlying aquifers and the sequestration capacity of gas reservoirs in Alberta have been published in the *Journal of Canadian Petroleum Technology, v. 41, no. 9, p. 51-61, 2002*, in the paper titled “Screening, Evaluation and Ranking of Oil Reservoirs Suitable for CO_2-Flood EOR and Carbon Dioxide Sequestration” by Shaw and Bachu, and in the *Journal of Canadian Petroleum Technology, v. 42, no. 9, p. 51-61, 2003*, in the paper titled “Evaluation of the CO_2 sequestration capacity in Alberta’s oil and gas reservoirs at depletion and the effect of underlying aquifers” by Bachu and Shaw.

Duration: April 2000 to March 2004

Funding Level and Funders: $ 240,000 Canadian from the Alberta Energy Research Institute and $30,000 from NRCan for operating expenditures. Approximately $330,000 Canadian of manpower-equivalent was provided by the Alberta Energy and Utilities Board.

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Sequestration of Carbon Dioxide in Oil Sands Tailings Streams

The objective of this project is to develop the fundamental understanding of carbon dioxide-oil sands tailings chemistry that will allow for the engineering of a co-storage process. The amount of CO_2 that could be sequestered in mature fine tailings from oil sands is only roughly estimated at this time (from 0.3 to 3 Megatonnes of CO_2 per year). The impact of carbon dioxide on process water chemistry needs to be understood in considerably more detail in order to confidently implement the consolidated tailings (CT) process with CO_2 instead of gypsum. Although preliminary results are very encouraging, long term tailings deposit stability has to be determined, along with the long-term water quality. There is also an opportunity for improved bitumen recovery from tailings during the mature fine tailings transfer process. The amount and quality of this bitumen needs to be defined since it could have an impact on the economics of any commercial implementation. Carbon dioxide could both reduce the amount of calcium required for the consolidation process and at the same time scavenge excess calcium as a calcite precipitate. The consolidated tailings (CT) process (commercialized at Suncor) involves the transfer of mature fine tailings (MFT), addition of gypsum, and mixing with coarse tailings to create a material, which can be eventually reclaimed as a soil. During transfer of MFT, bubbling CO_2 could be used to extract residual bitumen from the MFT, while absorption of CO_2 in the MFT would result in favourable properties relative to CT production. This manipulation of the MFT properties using CO_2 could result in a reduction of the gypsum requirement and ultimately reduce the ionic loading in the recycle water to the extraction process. Total CO_2 capture is approximately 100x greater for the preliminary trials and depending upon the rate at which physically sequestered CO_2 becomes chemically sequestered as carbonate and bicarbonate, these results suggest that chemical sequestration would be at a minimum 1200t/Mt for a conventional CT deposit. Conversion to carbonate and bicarbonate is unknown for the oil sands tailings, but conservatively, this could be as much as 10x greater. The fundamental studies will be carried out at the CANMET Energy Technology Centre - Devon, with technical input from industry personnel.

Duration: Oct 2001 – March 2005

Funding Level and Funders: $1M from CCAP (Canadian Federal Government), and $50K/year from Suncor Energy Inc., and Canadian Natural Resources Ltd (not including the cost of the large scale demonstration by CNRL).

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Preliminary results have been presented at the 2003 Canadian International Petroleum Conference, Calgary, and the 2003 Canadian Chemical Engineering Conference. Other publications will be available shortly, along with 2 CETC-Devon internal reports.

Suitability of Canada's Sedimentary Basins for CO_2 Sequestration

Sedimentary basins have various degrees of suitability for CO_2 sequestration in geological media as a result of different conditions and geological, hydrogeological and geothermal characteristics. The purpose of the project was to identify on a continental-scale the suitability of approximately 70 sedimentary basins in Canada for CO_2 sequestration in geological media. On a regional scale, the suitability for CO_2 sequestration of the Alberta basin and of the Canadian part of the Williston basin (shared with the US) was assessed both geographically and stratigraphically.

Duration: The project was completed at the end of 2002.

A set of 15 intrinsic and extrinsic criteria, with several classes each, has been developed for the assessment and ranking of sedimentary basins in terms of their suitability for CO_2 sequestration. Table 1, below, presents the criteria used in the assessment.

	Criterion	Classes				
		1	2	3	4	5
1	Tectonic Setting	Convergent oceanic	Convergent intramontane	Divergent continental shelf	Divergent foredeep	Divergent cratonic
2	Size	Small	Medium	Large	Giant	
3	Depth	Shallow (<1500 m)	Intermediate (1500-3500 m)	Deep (>3500 m)		
4	Geology	Extensively faulted & fractured	Moderately faulted & fractured	Limited faulting & fracturing, extensive shales		
5	Hydrogeology	Shallow, short flow systems, or compaction flow	Intermediate flow systems	Regional, long-range flow systems; topography or erosional flow		
6	Geothermal	Warm basin	Moderate	Cold basin		
7	Hydrocarbon Potential	None	Small	Medium	Large	Giant
8	Maturity	Unexplored	Exploration	Developing	Mature	Overmature
9	Coal & CBM	None	Deep (>800 m)	Shallow (200-800 m)		
10	Salts	None	Domes	Beds		
11	On/Off Shore	Deep offshore	Shallow offshore	Onshore		
12	Climate	Arctic	Subarctic	Desert	Tropical	Temperate
13	Accessibility	Inaccessible	Difficult	Acceptable	Easy	
14	Infrastructure	None	Minor	Moderate	Extensive	
15	CO_2 Sources	None	Few	Moderate	Major	

Table 1: Criteria for assessing sedimentary basins for CO_2 geological sequestration.

Using a parametric normalization procedure, a basin's individual scores are transformed into dimensionless scores that vary between 0 and 1, allowing thus inter-criterion comparisons. The weighed total scores of various groups of sedimentary basins in Canada were compared and ranked to determine the most suitable basin or region for the geological sequestration of CO_2. Table 2 presents the characteristics and rank of the main groups of sedimentary basins in Canada in terms of their suitability for CO_2 sequestration.

Rank	Basin(s)	Characteristics	Score
1	Alberta	Foredeep, giant, deep, mature, coals and salts, good infrastructure, temperate, large point CO_2 sources, large CO_2 emissions	0.96
2	Williston	Intracratonic, large, deep, mature, coals, good infrastructure, temperate, large point CO_2 sources	0.88
3	Beaufort-Mackenzie	Foredeep, large, deep, exploring, sub-arctic, large hydrocarbon potential	0.60
4	SW Ontario	Arch, shallow, small, overmature, good infrastructure, temperate, CO_2 sources	0.52
5	Atlantic shelf	Offshore, developing, oil and gas, coals, large CO_2 point sources	0.35
6	St. Lawrence River	Foredeep, small, temperate, CO_2 sources, no hydrocarbons and coals	0.31
7	Gulf of St. Lawrence	Off-shore, small, no CO_2 sources	0.26
8	Arctic islands	On/off shore, arctic, coals, no CO_2 sources and infrastructure	0.24
9	Intramontane	Convergent, small, coals, no CO_2 sources and infrastructure	0.20
10	Hudson Bay	Mostly offshore, intracratonic, subarctic, no potential, no CO_2	0.18
11	Eastern Arctic	Offshore, arctic, no potential no CO_2 sources	0.13
12	Pacific	Convergent trench, off-shore, un-explored, no CO_2 sources, no infrastructure	0.09

Table 2: Ranking of Canada's sedimentary basins in terms of suitability for CO_2 geological sequestration.

Details of methodology and application to Canada's sedimentary basins were published in *Environmental Geology, v. 44, p. 277-289, DOI 10.1007/s00254-003-0762-9, 2003*, in the paper titled "Screening and ranking of sedimentary basins for sequestration of CO_2 in geological media" by Stefan Bachu.

Funding Level and Funders: $270,000 Canadian from the federal government for operating expenditures, and matching funds for manpower from the Alberta government through the Alberta Energy and Utilities Board.

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Sustainable Coalbed Methane Production: Microbial Regeneration of Coalbed Methane Reservoir and CO_2 Conversion to Methane

The Alberta Research Council, Terralog Technologies Inc., IISOKM Geochemical Consultants Ltd., and RMB Earth Science Consultants Ltd., respectively, are developing technology to enhance biogenic methane production in deep, unmineable coal beds for clean energy generation.

While CBM recovery has been developed and operational for at least 15 years in the US, enhanced CBM (ECBM) is emerging as the next step in the evolution of the technology. ECBM could improve both production rates and the ultimate recovery of CBM gas. ECBM involves capturing and injecting CO_2 into deep, unmineable coal beds. The CO_2 absorbs into the coal and displaces the trapped methane. The CO_2 remains in the ground after completion of the methane production. This stored CO_2 could be biologically converted to methane leading to an underground closed-circuit methane factory.

It has been recognized in recent years that ongoing biogenic methane production, or methanogenesis, is occurring in many deep coal beds. As well, there are many methanogenic bacteria in nature, especially in the deep subsurface, that can convert CO_2 to methane. With the injection of CO_2 into the coal beds, indigenous methanogens or an introduced culture could reduce the CO_2 to methane. Access of the microorganisms to the stored CO_2 as well as stoichiometric amounts of the reducing equivalent, hydrogen, would be necessary. To ensure deep penetration of the introduced microbes and/or nutrients into low permeability coals, slurry-fracturing technologies such as those developed by Terralog Technologies Inc. can be used. The injection well would be shut in and a suitable length of time allowed for the methanogens to grow and produce methane before the methane is recovered by the production well. If necessary, nutrients can be introduced to the coal bed to stimulate microbial activity. In addition to microbial CO_2 reduction, the microbial decomposition of coal to methane by either indigenous or introduced consortia occurs concurrently (this is known as primary methane production).

The production of methane from coal in a sustainable fashion is, therefore, approached in a cyclic process that reduces CO_2 emissions to the atmosphere by injecting them into coal beds, producing methane trapped in coal and regenerating more methane from CO_2 and coal by bacterial action. The end result is that the coal decreases slightly in volume, permeability increases, and the coal can later be mined for other purposes.

Duration: 2002-2006

Funding Level and Funders: $300,000
Government of Canada
Province of Alberta
Private Industry

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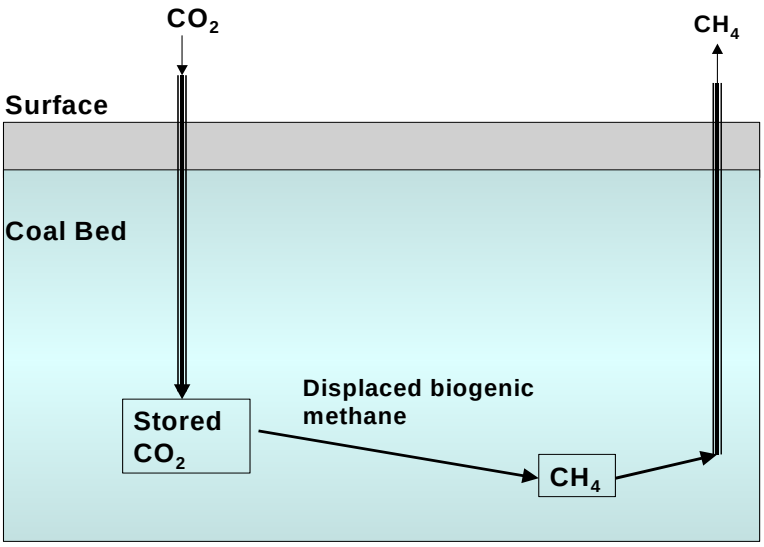
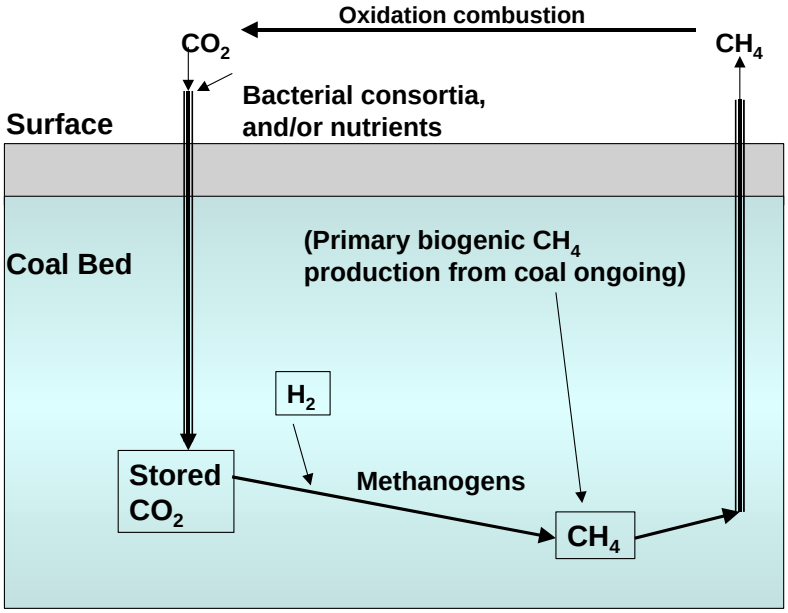


ECBM process



ECBM with microbial regeneration