Project Annex I - Weyburn CO_2 Sequestration Project
under the
Implementing Arrangement Between the
Department of Energy of the United States of America
and the
Department of Natural Resources Canada
for Cooperation in the Area of Fossil Fuels

Preamble

This Project Annex, between the Department of Energy of the United States of America (DOE) and the Department of Natural Resources Canada (NRCan), hereinafter the "Participants," is subject to the provisions of the Implementing Arrangement Between the Department of Energy of the United States of America and the Department of Natural Resources of Canada for Cooperation in the Area of Fossil Fuels, effective February 7, 2000, which is itself subject to the Memorandum of Understanding on Collaboration in Energy Research and Development between the Participants, signed on March 18, 1998.

This Project Annex establishes a framework and terms and conditions for the Participants' collaboration on the "Weyburn Carbon Dioxide Sequestration Project," which is designed to enhance understanding of underground sequestration of CO_2, where the CO_2 is made part of an enhanced oil recovery (EOR) process. The Participants expect the technology developed in this project, particularly in seismic monitoring and long-term modeling, will be of enormous significance to the establishment of geologic sequestration as a viable and publicly acceptable option for greenhouse gas (GHG) emissions control worldwide.

Section 1 - Background

The Weyburn Carbon Dioxide (CO_2) Sequestration Project (hereinafter the "Project") is a $27 million collaborative research project, involving many international participants, which is intended to expand the overall knowledge base of the capacity, transport, and storage integrity of carbon dioxide injected into geological formations. This objective will be accomplished through the scientific mapping of the movement of CO_2 in the selected reservoir, and a technical and mathematical prediction of the future long-term storage and migration characteristics of the CO_2. The field laboratory is the Weyburn CO_2 Miscible Flood EOR Project, located in southeastern Saskatchewan, near the U.S. border with North Dakota. The Williston Basin extends through parts of Manitoba, Saskatchewan, Alberta, the Dakotas, and Montana.

The miscible CO_2 EOR flood will be monitored from inception to conclusion. The Participants expect this Project will assist public policy makers, energy industries, and the general public by providing reliable information and analysis of the geological sequestration of CO_2 and its association with EOR.

Section 2 - Project Objectives

1. The Project's overall objective is to establish the degree of security with which carbon dioxide can be permanently and safely sequestered in subterranean geological formations worldwide. This Project involves the injection of CO_2 into a carbonate oil reservoir in the Williston Basin and will generate valuable information on understanding the combination of oil recovery and carbon dioxide storage.

2. The Project is expected to accomplish the following specific objectives:

   1) Apply the technology developed in the Project to selection of CO_2 storage sites, as well as design and successfully implement such storage projects;

   2) Predict the economic limits of cost-effective CO_2 storage. Results will be useful in assessing the value of this technology for use in previously abandoned or depleted oil fields. This technology may also be applicable for use in deep, saline aquifers in the Williston Basin which could provide extensive CO_2 storage potential far beyond that of oil fields.

   3) Make a credible assessment of the permanent containment of injected CO_2 determined by long-term predictive simulations and formal risk analysis techniques. Such an assessment will help answer questions by regulatory bodies as to the security of large volume CO_2 sequestration/storage not only in the Williston Basin, but also in other areas where geologically similar formations exist.

3. Additional background concerning the Project, together with specification of Project tasks, identification of Project supporters and participants, and anticipated allocation of Project financial contributions, are set forth in the Attachment which is appended to and constitutes an integral part of this Project Annex.

Section 3 - Project Intellectual Property

1. The Participants agree that all intellectual property arising from Project activities shall be governed by the Research Project Agreement between the Petroleum Technology Research Centre (PTRC) and EnCana dated June 15, 2000, and assert no ownership rights to Project intellectual property.

2. The Participants shall have an irrevocable, non-exclusive, royalty-free world-wide license in perpetuity to use Project intellectual property for any purpose whatsoever.

3. PTRC shall provide the Participants copies of all reports, documents and publications arising out of the performance of the Project and the Participants shall have the right to

publish all Project intellectual property for governmental, academic and educational purposes, policy formation, and make announcements respecting the Project.

Section 4 - <u>Management Plan</u>

The management of the Project will structured as follows:

1. NRCan has contracted with PTRC to serve as the manager of the Project, and the various principal task leaders will report directly to PTRC. PTRC will perform its management responsibilities in accordance with a Project Control Document developed by the Participants, and will report to a Management Committee (MC), which has been established for the Project.

2. The MC currently consists of one member each from NRCan, DOE's National Energy Technology Laboratory, PTRC, EnCana, and the Saskatchewan Industry and Resources, and the provincial government of Alberta. The total number of MC members and the composition of the MC may be altered by a simple majority of the MC.

3. Meetings of the MC will be held not less than four times per year, at locations to be determined by the MC.

4. The MC will be responsible for:

    1) approval of any significant changes to the Project;

    2) approval of any new research or organizations that have received funding to conduct research on the Project (hereinafter "Research Providers") (see Attachment, page 18);

    3) approval of terms and changes to any budgets for the Project;

    4) approval of all payments to the PTRC;

    5) replacement, if necessary, of PTRC as manager of the Project;

    6) approval of all reports and proposed publication of research results and Project intellectual property; and

    7) any other matters as the Participants agree to.

5. Any member of the MC may, with at least 5 Canadian business days prior written notice (unless any member not present at the meeting waives notice thereof in writing), call a meeting of the MC. Meetings may be held by telephone conference call. A quorum of

the MC for the conduct of business will be 75% of the designated representatives present in person or by telephone conference.

6. The MC will designate a chairman, who will serve in that capacity for one year at a time.

7. Each MC member will appoint one or two alternates, such that decisions may be made in the absence of the member.

8. A decision of the MC will be binding on the Participants and other members of the MC if it is taken in an MC business meeting and if it is evidenced by written minutes of the MC. Draft minutes will be available within 2 weeks of the meeting. Any corrections to the minutes must be made within a week.

9. Each year the MC will approve an annual firm allocation of funding to each Research Provider, taking into account the results of the previous work or new work to be undertaken

10. For each approved research task of a Research Provider, an Approval for Expenditure (AFE) will be prepared that outlines the specific work scope for the task by the Research Provider and by project year. The AFE is to be signed by the authorized representative(s) of the Research Provider and general manager of PRTC on behalf of the MC.

Section 5 - <u>Funding</u>

1. The total cost of the Project is estimated at approximately $US27,736,000, and includes in-kind contributions by the Research Providers (see Attachment, page 19).

2. The Participants anticipate that the costs of the Project will be borne by the Participants (subject to the availability of appropriated funds), and by cash and in-kind contributions, by the entities named and in the amounts set forth in the Funding Schedule set out in the Attachment.

3. The Participants will make their respective contributions to the Project in accordance with a mutually agreed schedule.

4. DOE reserves the right to have its financial contributions applied to specific project research activities. Subject to MC approval, other sponsors may direct their funds to specific research activities.

Section 6 - Dissemination of Project Information

1. The information derived from this Project is expected to be of global significance with respect to proving that carbon dioxide emissions from fossil fuel combustion sources can be cost effectively reduced. The Project Manager will disseminate the results of the Project to the Participants and to oil and gas producers in the Williston Basin, generally to the oil and gas industry in the U.S. and Canada, and to policymakers and regulators in U.S. state and Canadian provincial governments concerned with energy production and carbon dioxide emissions control. The Participants anticipate that the International Energy Agency Greenhouse Gas Research and Development Programme will disseminate the results of the Project to researchers in many different nations.

2. The Participants intend that the Research Providers will cooperate and collaborate with researchers performing related research in other public/private projects supported by the Participants and governments involved in funding this Project. Subject to approval of the MC, this collaboration would include information exchanges and participation in experts workshops and other joint activities, in particular the British Petroleum (BP) managed Carbon Capture Project (CCP).

Section 7 - Amendment of the Project Annex

The Project Annex may be amended by written agreement of the Participants.

Section 8 - General Provisions

1. Each Participant shall conduct the collaboration under this Project Annex in accordance with the applicable laws and regulations under which each Participant operates.

2. Any questions arising in connection with the interpretation or implementation of this Project Annex shall be resolved through consultation between the Participants.

Section 9 - Effective Date and Termination

1. This Project Annex shall become effective upon signature and shall remain in effect for the duration of the Project, so long as the Implementing Arrangement remains in effect. The Parties may extend this Project Annex by written agreement.

2. Either Participant may terminate this Project Annex at any time upon 6 months written notice to the other Participant.

SIGNED in duplicate in the English and French languages, each text being equally authentic.

FOR THE DEPARTMENT OF ENERGY
OF THE UNITED STATES OF AMERICA:

Date: 9/4/02

Place: Washington D.C., USA

FOR THE DEPARTMENT OF NATURAL
RESOURCES CANADA:

R. J. Cam

Date: 9/11/02

Place: Ottawa, Ont. Canada.

Attachment to
Project Annex I - Weyburn CO2 Sequestration Project
Under the
Implementing Agreement Between Department of Energy of the
United States of America
and the
Department of Natural Resources Canada
for Cooperation in the Area of Fossil Fuels

Background

During 2000, EnCana (formerly Pan Canadian Resources), a major Canadian oil company began a large EOR project in the Weyburn field of southeastern Saskatchewan using miscible CO_2 injection. This project, which is the largest EOR project in Canada, is expected to produce at least 130 million barrels of incremental oil from a field that has already produced 335 million barrels since its discovery in 1955. Over the course of the project, some 20 million metric tons of CO_2 will be sequestered beneath the field surface. The fossil fuel derived CO_2 for this project will be supplied by the Great Plains Synfuels Plant[1]. The CO_2 can be delivered to Weyburn for half the price of comparable Canadian flue gas-based CO_2 sources. The Dakota Gasification Company has constructed a 204 mile pipeline that began operation in August 2000. It is currently delivering 5000 tons/day of nearly pure CO_2, as originally planned, to the Weyburn field. The pipeline is sized such that additional carbon dioxide from Great Plains could eventually be supplied for other EOR/carbon dioxide sequestration projects throughout the Williston Basin, which extends through parts of Manitoba, Saskatchewan, the Dakotas, and Montana.

Program Scope and Task Allocation

This project will require well coordinated efforts involving a diverse range of highly specialized scientific services. The elements needed to achieve the overall objective will include field production and analytical data; comprehensive geological modeling; assessment of geochemical changes occurring in the various formation fluids and the reservoir rock itself; seismic monitoring of the movement of the various fluids including the development of new technology to allow this to occur; fluid and phase behavior characterization; sequestration science and

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[1]The Great Plains Synfuels Plant is the only commercial-scale coal gasification plant for pipeline gas production in the United States. Located five miles northwest of Beulah, North Dakota; the synfuels plant has been owned and operated by Dakota Gasification Company, a subsidiary of Basin Electric Power Corporation, since 1988. DOE has been a major supporter of this $2.1 billion plant since its inception. The plant currently produces 12,600 tons of CO_2/day (200 million cubic feet of CO_2/day) as a byproduct of its coal gasification plant operation, which produces 160 million cubic feet of synthetic natural gas/day.

research applied to the development of better monitoring tools and techniques; and most importantly, the numerical modeling of the long-term migration behavior and fate of sequestered CO_2.

Each activity undertaken will be conducted under the supervision of the most knowledgeable authorities available in each of their subject areas. The identified leaders will be nationally or internationally recognized and will be chosen on the basis of their established records of experience in research and project coordination for the region under study. The information from each of the above topics of investigation will be integrated through both the sharing of periodic progress reports and meetings. The resulting information will be incorporated into a report describing the forecasts of sequestration behavior.

Task 1 –Collection of Field Data and Samples

This task encompasses the collection of data and field samples that require the participation of the field operator's staff.

Sub-task 1.1 – Liaison, Field Support and Reporting

1. Designate a representative to liaise with Project Director for timely flow of data to Research Providers and to address all project issues.

2. Assign staff (200 person weeks over 4 years – i.e. 1 person-year/year average) to gather, assemble and distribute field and other data to Research Providers, hold technical discussions and co-ordinate respective activities.

3. Provide data reports and regular progress reports to Research Providers.

4. Conduct 3D seismic field program

Task 2 – Geoscience Framework

The geological characteristics of the Weyburn field and surrounding region will be identified and cast into a comprehensive model that describes the rock properties and physics that govern fluid movement and storage in the target and neighbouring formations. The model will be assembled through the investigation of both existing regional seismic data, the examination of the extensive core library in storage with Saskatchewan Industry and Resources, and the use of well logs, most of which are available for public use. The model will include determination of the hydrogeological behaviours expected within these formations.

Sub-task 2.1 – Influence of pre-Mississippian Regional Geology On Structure and Conductivity of Reservoirs within a 100 km Radius of the Weyburn Project.

Augment regional geoscience framework of the area of interest through:

1. Mapping and interpretation of pre-Mississippian strata, with emphasis on deposition and dissolution of evaporates.

2. Determining the influence of the geological evolution of pre-Mississippian strata on the sedimentology, diagenesis, porosity and permeability in Mississippian reservoirs.

Sub-task 2.2 – Regional Hydrogeology

1. Quantify regional hydrogeology (3-D flow field in terms of rates, directions, etc.) in the area of interest through:

    a. Creation of a hydrostratigraphic framework (aquifers and aquitards) for the area surrounding the Weyburn reservoir. Assign hydraulic properties to the hydrostratigraphic units(porosity, permeability, thickness, etc).

    b. Map the distribution of fluid potential in each hydrostratigraphic unit, using fluid pressures culled for production effects and poor quality data.

    c. Map the distribution of hydrochemical facies and TDS for each hydrostratigraphic unit, using hydrochemical data.

    d. Map the distribution of temperature for each hydrostratigraphic unit.

    e. Estimate the fluid flow rates and directions in each hydrostratigraphic unit using the calculated fluid potentials and hydraulic conductivities.

2. Integrate the plan view maps into a 3-D picture of fluid flow using Pressure-Depth plots, and hydrochemical tracers to infer any potential cross-formational flow pathways.

3. Identify any potential "leakage" pathways for CO_2 in the system.

Sub-task 2.3 – Reflection Seismic Investigations

Augment regional geological framework of a 100-km radius area around Weyburn through:

1. reprocessing existing seismic reflection and wireline information.

2. determining unknown petrophysical properties through inversion of the seismic data and attributes of the well log information.

Sub-task 2.4 – Influence of the Mississippian and post-Mississippian Regional Geology on Structure and Conductivity of Reservoirs within a 100 km Radius of the Weyburn Project.
Augment regional geological framework of the area of interest through the study of:

1. sedimentology and diagenesis of Mississippian carbonates and the impact on capacity to sequester CO_2;

2. nature of the post-Mississippian unconformity surface and its control on fluid distribution;

3. geology of the aquifers in overlying Jurassic and Cretaceous strata and the potential for communication with the Midale Beds and thus escape of CO_2.

The results of proposed project will provide information on regional geology and its influence on porosity and permeability in Mississippian reservoirs to identify the migration pathway for the injected CO_2 and to forecast possible cross-formational fluid flow or leaking of injected CO_2.

Sub-task 2.5 - Geoscience Synthesis

Establish a comprehensive geoscience framework to help identify controls on CO_2 migration and storage through:

Ongoing, practical co-ordination of the four geoscience framework studies (hydrogeology; reflection seismic; pre-Mississippian geology; and Mississippian and post-Mississippian geology)

Integration and analysis of all available geoscience datasets regarding tectonics, sedimentation digenesis and fluid flow.

Sub-task 2.6 - Remote Sensing

Within a 100- km radius of the Weyburn Project:

1. Identify remotely sensed features, especially surface lineaments, that will assist mapping of subsurface fracture zones, faults and associated geological structures.

2. Identify remotely sensed features, especially surface lineaments, that will assist mapping local fracture-related structures that may influence movement of CO_2 injected in the Weyburn pool.

3. Integrate air photo and satellite imagery data with geological, geophysical and geochemical data.

Task 3 – Geochemical Sampling, Monitoring and Prediction

The effects of geochemistry will be determined, including the effects of carbon dioxide-rock reactions that will influence fluid flow, CO_2 storage capacity, and formation stability.

Sub-task 3.1 – Baseline Information Gathering

Establish the baseline chemical and isotopic conditions of the Weyburn Reservoir through chemical and isotopic analyses of minerals, aqueous fluids and gases. These will be used as a baseline to establish if/when CO_2 breakthrough occurs and to provide the basis for modeling the physical trapping and chemical sequestration of CO_2 in the reservoir.

Sample reservoir fluids (water and gas), both formation and those injected pre-CO_2 flood from approximately 50 selected wells according to a sampling plan.

Conduct geochemical analysis on well fluid samples including major cations and anions concentrations, and carbon isotopic measurements.

Establish the area to be sampled and frequency of sampling for the post-injection monitoring phase.

The mineralogy and isotopic distribution in the Weyburn reservoir and the cap rock will be characterized through 100 petrographic thin section analyses, 100 XRD major elemental analysis and 100 SEM analyses. 50 samples will be selected for mineral isotopic determination and 25 samples will undergo detailed microprobe analysis.

Sub-task 3.2 – Geochemical Monitoring

Monitor the position/breakthrough of the CO_2 front through chemical monitoring at the producing wells; conduct experiments to demonstrate the possible chemical sequestration of CO_2 and to establish the rates (kinetics) of the chemical reactions which can affect CO_2 sequestration and storage; measure surface solid gas composition in order to confirm there is no leakage occurring.

1. Sample produced fluids and analyze as in 3.1 with emphasis on the isotopic composition of CO_2 and major element chemistry. Correlate where possible with PRC's tracer program and the seismic monitoring programs by Lawrence Berkeley National Laboratory (LBNL), University of Alberta (U of A), University of Calgary (U of C) and Colorado School of Mines (CSM). The results will be used to indicate possible incipient breakthrough of CO_2 and as input for the geochemical (3.3) and reservoir modeling for calibration, verification and prediction purposes (U of C). Quality control maintained by duplicate samples to European Union (EU) participants.

2. Conduct lab experiments to quantify short and long term chemical changes in the reservoir and the cap rock. The experiments will consist of autoclave runs (static mixtures of CO_2, water and minerals) for scoping purposes and core floods (dynamic experiments where CO_2 and water mixtures are pumped through a jacketed core). In the autoclave experiments, initial and final fluid compositions and mineralogy is determined while for the core floods, out-flow fluid compositions are continuously monitored.

The result will be used to directly demonstrate the amount of CO_2 sequestration over the experimentation period and to provide rate (kinetic) data for use in the geochemical modeling.

3. Monitor soil gas composition to detect ground surface leakage. This will be done by vacuum sampling gas in the soil and measuring gas composition using a portable gas sampler. Some samples will be taken and shipped back to the laboratory for more detailed analysis. Results will be compared to world and local baseline then used to detect if leakage to the surface is occurring.

Sub-task 3.3 – Reservoir and Regional Geochemical Modeling

Using geochemical models, thermodynamic and kinetic data, predict the short-term (25 years) chemical impact of CO_2 flooding on reservoir properties, the recovery process and the production equipment, and predict the long-term (1,000 to 10,000 years) chemical impact on CO_2 sequestration through dissolution and precipitation of minerals locally in the Weyburn field and regionally. The goal is to identify if permanent sequestration occurs through the precipitation of carbonate minerals such as calcite in the basin.

The modeling will be carried out in parallel by a number of international groups using a common kinetic database. This allows:

1. Model verification across different platforms and numerical methods.

2. International exposure of the program.

3. Buy-in by the international community under the auspices of the International Energy Agency Greenhouse Gas Research and Development Programme.

4. Increased range of evaluation.

5. Allow easier extrapolation of the data and methodology to other sites.

Changes in reservoir and cap rock properties from the action of CO_2 on the reservoir and cap rock mineralogy and from the mixing with regional groundwater, for both the short term (up to 25 years) and long term (up to 10,000 years) will be calculated as follows:

1. Short Term: Geochemical modeling to evaluate the position of the CO_2 front, the modification of reservoir properties and the potential of mineral scaling in the production equipment will be calculated. These changes are the result of reactions between CO_2 and the reservoir mineralogy and fluids, and will largely be dominated by reactions involving carbonate minerals. The results will be compared to and validated with the field data (all modelers). The focus of the short term modeling is on the Weyburn reservoir and the cap rock.

2. Long Term: Geochemical modeling will be undertaken to predict the long term (1,000 to 10,000 years) nature of CO_2 sequestration in the Weyburn field, the surrounding units and the regional area. The storage will be dominated by reactions driven by disequilibria with the silicate minerals, the injected fluid and the regional groundwater.

3. A kinetic database will be developed to provide the thermodynamic and rate information necessary for the long term geochemical calculation and prediction of reactions in the Weyburn reservoir and cap rock. The database will provide a common basis for all geochemical calculations. The nature of the data is general, and will be applicable to any other site involving the use of CO_2.

Sub-task 3.4 - Reservoir Integrity

Establish the integrity of the reservoir through examination of the cap rock, bottom "seal" and well bore.

1. Characterization of cap rock integrity under conditions of CO_2 injection. This will provide the fundamental information to determine if CO_2 injection will cause cap rock failure and leakage of CO_2. Full compression/shear wave measurements will be made on several core samples over entire stress strain curve. This will allow the stress-strength-permeability variations of the cap rock to be determined. The results will be integrated with the geochemical modeling studies

2. Well bore integrity will be assessed through modelling studies of borehole cements, corrosion studies and evaluation of mechanical stability.

Task 4 – Monitoring CO_2 Movement

This task consists of the gathering of seismic and electromagnetic data at carefully pre-selected sites over time to refine the state-of-the-art seismic methods for cost-effective tracking of CO_2 migration, and to establish the movement of carbon dioxide within the reservoir for the first two years after CO_2 injection commences. LBNL and CSM will coordinate the work of the individual proponents, and insure that no overlap of responsibility occurs, and that information and data are shared in a timely manner.

Sub-task 4.1 – Integration of High Resolution Active and Passive Borehole Seismic Imaging for tracking CO_2.

Description: Conduct time-lapse borehole seismic and electromagnetic surveys to refine state of the art LBNL seismic techniques and in turn track CO_2 movements for the first two years of the flood. The plan is:

1. Conduct crosswell seismic surveys on one or two well pairs at 250 m spacing in the migration path of the CO_2 before CO_2 injection and repeat twice a year after CO_2 injection.

2. Conduct electromagnetic (EM) time-lapse surveys to monitor fluid saturation changes.

Sub-task 4.2 – High Resolution, 4-D Surface Seismic for Tracking CO_2.

Description: Conduct time-lapse surface seismic surveys to refine state-of-the-art CSM seismic techniques and in turn, track CO_2 movements for the first two years of the flood. The plan is:

1. Analyze PCR's seismic survey conducted in late 1999 to augment the pre-injection database.

2. Conduct vertical seismic profile (VSP) and compare resolution to the crosswell data.

3. Conduct time lapse, 4-D, 9-C surface seismic surveys over a four well pattern for approximately three years to provide details of CO_2 migration patterns.

4. Integrate the seismic surveys data with geological and reservoir models to improve short and long term predictions of CO_2 distribution.

5. Conduct passive seismic monitoring using downhole geophones to measure any microseismicity and augment the results of the active seismic monitoring.

Sub-task 4.3 – Microseismic Monitoring of CO_2

Description: Conduct continuous, passive, micro seismic monitoring within the initially flooded 19 well patterns and if successful, interpret results and augment information from the borehole seismic in sub-task 4.1.

Once instrumentation is placed in the field, monitoring will continue until the end of the project or until equipment failure.

Task 5 – Sequestration Performance

This task integrates results of all the studies related to the assessment of the performance of CO_2 flood as determined from the characteristics of observed production streams, and the forecasting of both the field performance, and the regional migration/sequestration behaviour of the injected CO_2. Many of the program tasks involve development and improvement of specific technologies with hope of proving up these technologies by the end of this monitoring project.

Sub-task 5.1 – Project Co-ordination

Plan, coordinate, and execute the project in collaboration with all Research Providers and their principal task leaders and facilitate the distribution of information to all participants and sponsors.

Sub-task 5.2 – Laboratory Dynamic Fluid Testing

Evaluate the displacement performance of the CO_2 flood by determining whether the displacement is miscible, near-miscible or immiscible over the first four years of production in the initially flooded 19 well pattern, as follows:

1. Obtain fluid samples monthly from two production wells in different patterns.

2. Analyze the composition; recombine at reservoir conditions to obtain bubble point, viscosity and density.

Sub-task 5.3 – Reinjection of Recycled CO_2

Determine the impact of the changing composition of the oil and recycled gas (CO_2, methane, H_2S) on oil recovery and CO_2 movement as follows:

1. Monthly, conduct minimum miscibility pressure (MMP) measurements to detect if there is a miscibility loss and, if so, to correct it.

2. Every three months, conduct core floods on reconstituted fluids to determine effect of recycled impure CO_2 on oil recovery factor.

3. Conduct numerical simulation to match the core flood results to understand the impact of dynamic change of MMP on CO_2 distribution.

4. Incorporate the mechanism into field scale simulation.

Sub-task 5.4 – Numerical Simulation to Support CO_2 Monitoring

Conduct subset reservoir simulation to predict the movement of CO_2 front, the distribution of CO_2, and ensure a consistent and comprehensive understanding of CO_2 sequestration/storage mechanics. This study will involve working closely with other monitoring tasks and integrating data obtained from seismic imaging, wellbore fluid sampling, geochemical monitoring, and production operation. The simulation will concentrate initially on one 9-spot pattern where monitoring data are available. Additional individual patterns will also be simulated once confidence in "mechanistic" simulation has been established. Simulation will include sensitivity study testing the effect of other operation strategies on CO_2 sequestration. The results of small-scale simulations provide the boundary conditions for the subsequent long-term regional simulations. This will be done as follows:

1. Obtain reservoir information and operating history from EnCana. Compare capabilities of the STARS from CMG and the ECLIPSE 300 from GeoQuest-Schlumberger. Select one that is more applicable (temperature, solubility of CO_2 in water, chemical reaction, dynamic change of solubility in oil). Conduct history match to obtain baseline fluid distributions.

2. Predict the propagation and distribution of CO_2. Study the mechanism by looking at detailed development patterns.

3. Calibrate and verify the simulation results using data obtained from tracer, seismic, wellbore fluid sampling, geochemical monitoring, and production operation.

4. Modify model as necessary using results from Sub-task 5.2 and 5.3.

5. Once model is validated, study the effect of different operation strategy on CO_2 sequestration in a number of patterns.

6. Provide input data to 5.5, assessment of CO_2 sequestration.

<u>Sub-task 5.5</u> – Assessment of CO_2 Sequestration at the Weyburn Site

Assess the long-term (hundreds to thousands of years) fate of CO_2 injected into the Weyburn reservoir as follows:

1. Use rigorous and formal systems analysis (QA defensible - as used in radioactive waste disposal) to generate three credible scenarios for the evolution of the site over the long term.

2. For these three scenarios, conduct long-term numerical simulations, using input from other tasks, to determine the amount of CO_2 which will be transported to the atmosphere and to ground water as a function of time - effectively involves integration of data/results from the other tasks (geological, hydrological, geochemical, reservoir and fluid properties, simulations, etc.).

3. Conduct sensitivity analysis to establish the key modeling parameters; bracket the uncertainties of these parameters.

4. Evaluate the overall success of the CO_2 storage (the portion of CO_2 injected that will be retained permanently underground).

5. For public perspective and acceptance, compare CO_2 fluxes from Weyburn sequestration/storage (variability of atmospheric CO_2 fluxes) with relevant natural systems (e.g., volcanic activity).

<u>Sub-task 5.6</u> –CO_2 Mobility Control

Evaluate the fundamentals, performance and placement of commercially available systems for CO_2 mobility control through lab experiments and field trials.

Task 6- CO_2 Storage Economics

Establish a comprehensive economic model to compare the relative merits of incremental oil recovery and CO_2 sequestration for the Weyburn enhanced oil recovery project. Use the economic model to conduct a number of economic analyses/sensitivity studies for different injection and production strategies and assess their impact on oil production and CO_2 sequestration.

Project Supporters

This project is supported by EnCana, a prominent international Canadian petroleum producer that operates the Weyburn field, by the Dakota Gasification Company, the supplier of CO_2 to the Weyburn field site, Saskpower (Saskatchewan power utility company), Nexen (formerly Wascana Energy), BP (USA), Transalta (Alberta power utility company), Totalfinaelf (France), Statoil (Norway), ENI (Italy), Shell International, ChevronTexaco, Engineering Association of Japan (ENAA), European Community, the International Energy Agency Greenhouse Gas Research and Development Programme, and by the Petroleum Technology Research Centre (PTRC), which will coordinate and manage the efforts of the various research teams.

The current Research Providers include the following:

Canada
Saskatchewan Industry and Resources
Saskatchewan Research Council
University of Regina
University of Saskatchewan
Mollard & Associates
University of Alberta
University of Calgary
Alberta Research Council
EnCana

United States
Lawrence Berkeley National Laboratory
Colorado School of Mines
Monitor Scientific, Inc.
North Dakota Geologic Survey

European Community
British Geological Survey - United Kingdom
Bureau de Reserches Géologiques et Minières, France
Danish Geological Survey, Denmark
National Institute of Geoscience, Italy
Quintessa Limited, United Kingdom

Duration of Project
To June 2005

Funding

Total value of the project is estimated at approximately $27,736,000 in U.S. dollars and includes in-kind contributions by the Research Providers. The cost of the Project will be shared as follows:

Organization	Amount (US$)	Nature of Contribution
Government of Canada	$3,744,000	Cash
Government of Saskatchewan	$1,536,000 $200,000	Cash via SPRI Program In-kind Contribution
Government of Alberta	$380,000	Cash
PTRC	$67,000	Cash
EnCana	$64,000 $7,200,000	Cash In-kind Contribution
Saskpower Wascana BP Transalta Totalfinaelf Statoil ENI Shell International Chevron/Texaco	$192,000 $192,000 $192,000 $192,000 $192,000 $192,000* $192,000* $192,000* $192,000*	Cash[1/]
Dakota Gasification Company	$192,000	Cash[1/]
Engineering Association of Japan (ENAA)	$192,000	Cash
European Community	$1,933,562	Combination Cash and in-kind flows to European Researchers only
U.S. Department of Energy/ National Energy Technology Laboratory	$4,000,000	Cash[2/]

[1/] Contributions over a four year period
[2/] Contributions over a three year period.
*Pending