An International Research Project with Significant Economic Implications to North Dakota and the World:

NDGS Provides Part of Geologic Framework for Weyburn Project

by Randy Burke

Introduction

The North Dakota Geological Survey is participating in an international research investigation known as the Weyburn CO_2 Monitoring Project. This research project is designed principally to test the economic viability of injecting a "greenhouse gas", carbon dioxide (CO_2), underground into an aging oil reservoir. Underground injection of CO_2 into such reservoirs has two benefits: (1) it can greatly increase oil recovery from aging oil fields and (2) it may geologically sequester (permanently store) CO_2 in the subsurface thereby reducing the amount of man-made CO_2 entering the atmosphere. Results from the project will serve as a foundation for developing international protocols for monitoring geologic storage of CO_2 and for evaluating the use of greenhouse gas credits to improve the economics of using CO_2 for enhanced oil recovery. The project provides the NDGS with a tremendous opportunity to substantially refine our knowledge of the geologic framework and rock characteristics of a part of the Williston Basin.

World-class scientists from the United States, Canada, and the European Community are joined under the auspices of the International Energy Agency to test a plan that addresses both business and environmental concerns surrounding the generation and buildup of CO_2 in Earth's atmosphere. The plan is to sequester CO_2 underground in depleted or mature oil reservoirs. The test is to determine if this can be done effectively and economically. The experimental design is to capture man-made CO_2, to inject this gas into an aging oil reservoir to enhance recovery of additional oil, and to sequester the CO_2 in underground reservoirs.

Currently, many industries produce CO_2 as a byproduct. Some CO_2 is released into the atmosphere, and some people have attributed climatic change, in part, to an increase in atmospheric CO_2. This project examines a case where CO_2 is captured as a byproduct from an industrial process (the production of synfuels at the Dakota Gasification plant in Beulah, North Dakota) and sold to the petroleum industry. The petroleum industry uses the CO_2 to enhance oil recovery by pumping it into old oil reservoirs, thereby increasing the movement of oil out of the reservoir and greatly increasing the longevity and economic viability of the reservoir.

On the environmental front, this type of injection program decreases the amount of CO_2 being released into the atmosphere. The project has the potential to be a win-win-win plan. Industries that produce CO_2 win because they can increase revenues by selling a byproduct, the petroleum industry wins because it uses CO_2 to recover more oil, and the environment may benefit because less man-made CO_2 is released into the atmosphere as a result of such projects. The coal and oil industries could partner as sellers and buyers in the trade of CO_2 credits.

The Weyburn Field, located about 40 miles from the North Dakota border in Saskatchewan, Canada, was selected for the test project (Fig. 1). Saskatchewan Industry and Resources (SIR) invited the North Dakota Geological Survey to participate in the project by providing the detailed geoscience framework for the part of the Weyburn study area that extends about 38 miles into North Dakota.

Participation in the project allows the North Dakota Geological Survey early access to results from the project as they become available while honoring the proprietary rights

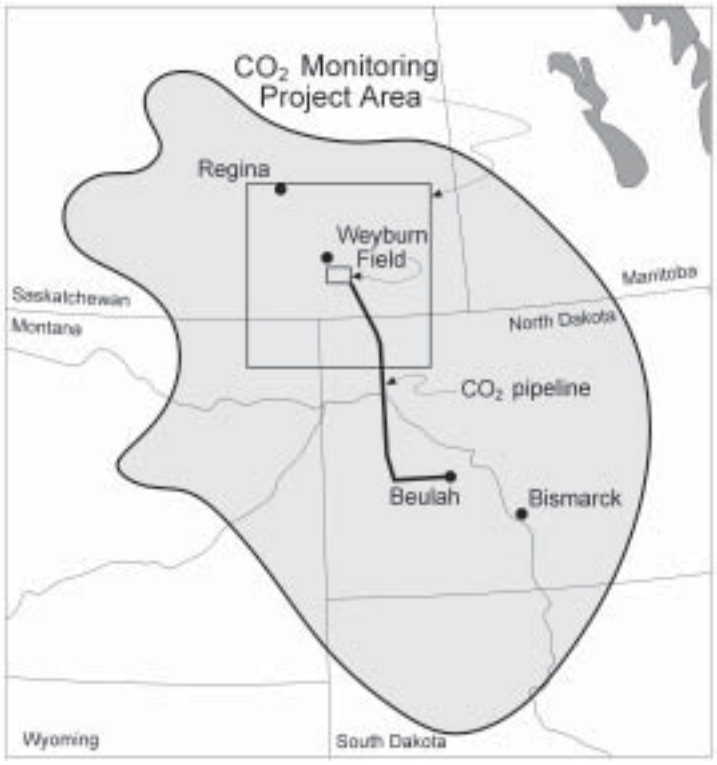

Figure 1. Map showing the location of Weyburn Field and the pipeline that carries CO_2 from the Coal Gasification Plant near Beulah, North Dakota, to the oil field. The location of the Williston Basin is the large shaded area.

of industry partners involved in the project. Should the test be successful, the initial economic benefits will come from using CO_2 generated by the Dakota Gasification Company for enhanced recovery operations to produce oil not otherwise recoverable from North Dakota's aging oil fields. Currently there are no CO_2 enhanced oil recovery projects in North Dakota. The economic viability of this technology to Williston Basin reservoirs is already being realized in the Weyburn Field where oil production has increased by 27%, or 4,500 barrels of oil per day. Should trade in CO_2 credits prove workable, additional power plants that use lignite could be built, requiring more power transmission lines to be constructed, and wind generator farms could expand. This project will provide answers to many questions that may be extremely beneficial to the environment, as well as to the oil, lignite, and power generation and transmission industries operating in North Dakota.

Weyburn Project

Mounting global concerns over the increase of greenhouse gases has been expressed at the Earth Summit and in the ensuing Kyoto Protocol. Consequently, the International Energy Agency (IEA) undertook the promotion of a global energy policy by assisting projects that integrate environmental and energy policies. Government, industry, and academic leaders from Canada, the United States, and the European Community prepared a joint proposal, coordinated and managed through the Petroleum Technology Research Center in Regina, Saskatchewan, to use Weyburn Field as a pilot project under the Green House Gas Research and Development Program of the IEA.

The sponsors (Table 1) and research providers for the project are budgeting over $41 million Canadian dollars in funds and services for the project. Of the cash contributions, the US Department of Energy provided 30%, Natural Resources Canada, 29%, European Community (Britain, France, Denmark, and Italy) 15%, Saskatchewan Industry and Resources 12%, and eight industry partners (including Dakota Gasification Company) 11%. The North Dakota Geological Survey is making "in-kind" contributions as one of the research providers. In the United States, other research providers include Lawrence Berkeley National Laboratory, Colorado School of Mines, and Monitor Scientific. Canadian research providers are Saskatchewan Industry and Resources, Saskatchewan Research Council, the universities of Alberta, Calgary, Saskatchewan, and Regina, the Alberta Research Council, Geological Survey of Canada, EnCana Corporation, and J.D. Mollard and Associates Limited. European research providers are the British Geological Survey, the French Bureau of Geological Research and Mines, the Danish Geological Survey, and the Italian National Institute of Geology.

Weyburn Field was selected for a number of reasons including easy access, a substantial amount of baseline data, numerous wells, and in large part, because the operator of the field, EnCana Corporation, was a supportive partner that already was initiating a major CO_2 enhanced oil recovery project with a $1.5 billion budget. Weyburn Field occupies 70 square miles and is calculated to have 1.4 billion barrels of oil in place, of which 350 million have been recovered. Injecting CO_2 is expected to produce an additional 120 million barrels of oil.

Basin Electric's Dakota Gasification plant is contracted to provide up to 95 million standard cubic feet of CO_2 per day for injecting into Weyburn Field. The sale of this gas is anticipated to gross approximately $30 million US per year for the next several years. One of the keys to this project was the construction of the gas pipeline from Beulah, North Dakota, to Weyburn, Saskatchewan, which was completed in 1999 (Fig. 1).

Since injection of CO_2 began in September of 2000, over 34 billion cubic feet of CO_2 have been injected into the Weyburn reservoir. The response to injection has been observed in 23 wells, and it has resulted in a 27% increase in production. This is an additional 4,500 barrels of oil per day that most likely would not have been recovered had this technique not been employed.

To determine if CO_2 can be sequestered, many questions never asked before must be addressed, and new technologies must be developed to answer many of them. We must learn what form, or forms, CO_2 takes after injection (solid, gas, or liquid), where it goes, and if there are any leaks currently in the reservoir or if any leaks may develop in the future. To accomplish this, the project was broken into six broad tasks: 1) field support and coordination; 2) geology; 3) geochemistry; 4) monitoring CO_2 movement; 5) storage performance; and 6) storage economics.

The North Dakota Geological Survey is participating in Task 2 by establishing the geologic framework for the parts of the Weyburn study area in North Dakota and Montana (Fig. 1). We divided the geologic column into fourths with Julie LeFever working on all rocks younger than Mississippian, Tom Heck on the Mississippian rocks, Randy Burke on the Devonian and

Table 1
Weyburn Project Sponsors

US Department of Energy	SaskPower
Natural Resources Canada	Nexen Canada
European Community	TotalFinaElf
Saskatchewan Industry and Resources	British Petroleum
EnCana Corporation	TransAlta Utilities
Dakota Gasification Co.	ENAA (Japan)
Petroleum Technology Research Center	Alberta Energy Research Institute

Silurian rocks, and Paul Diehl on the Ordovician and Cambrian rocks. Our work involves defining over one hundred different geologic boundaries from well logs from approximately one thousand wells. Funds from the Weyburn project were used to purchase a large amount of specialized data and some technical software for the NDGS so that we could accomplish our task. Figure 2 is an example of one of the types of maps produced from our data when combined with those data from Saskatchewan. This work has refined the correlation of geologic boundaries between Saskatchewan and the United States. Continued refinement of these correlations is necessary to understand the Williston Basin as a geologic entity unfettered by political boundaries.

Geologic knowledge of the North Dakota portion of the study area is fundamental to understanding the lateral and vertical variability of rock units containing the oil reservoir, as well as the rock strata above and below the reservoir. The rock units above and up-dip laterally to the reservoir provide the top and lateral seals that trap the oil and the carbon dioxide, thereby forming the reservoir. Rock units below and laterally down dip provided the conduits for the oil to migrate into the reservoir. Careful geologic and hydrologic mapping of the reservoir has shown that there is a hydrodynamic component to the oil trap at Weyburn. This requires that the dynamics of the aquifers in this part of the basin be understood. The conduits, or aquifers, that transmit fluids need to be determined to know where the CO_2 will be moving if it does not chemically bind with the host rocks.

Geologic data from North Dakota also provide information about regional and local faults, the behavior of the rocks near these faults, and the possible continuity of faults into the reservoir. Faults can allow fluids to migrate between permeable formations, so it is important to understand the aquifers, in part because of their potential for dissolving soluble minerals such as salt (Fig. 2). Indication of salt dissolution of the Prairie evaporite beneath North Dakota, Montana, and Saskatchewan can be seen on the isopach (thickness) map (Fig. 2) prepared for this project.

The details from our mapping will be combined with the

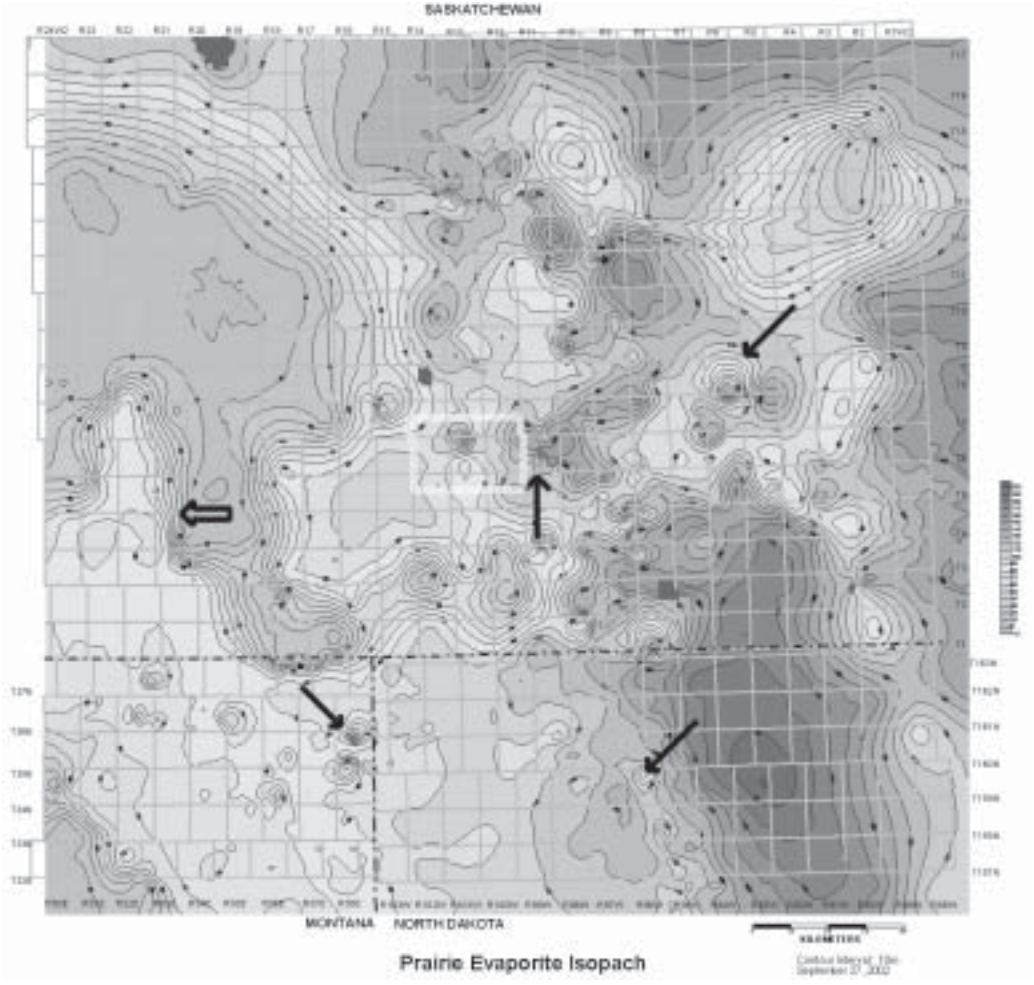

Figure 2. Map illustrating the thickness of the Devonian age Prairie Evaporite Formation that contains salt. Narrow arrows point to localized dissolution of salt that forms "holes" or thin areas (light grey subcircular areas) in the surrounding thicker (darker areas) salt. Open arrow points to a fault on the west side of a large, southeast-trending trough formed by more regional dissolution of salt. The contour interval for the thickness of salt is 32.8 feet (10 meters). The Weyburn Field area is outlined by white box.

results of the other geoscience tasks to make a detailed 3-D picture of the entire study area. It will be similar to the one developed for Weyburn Field (Fig. 3) by EnCana Corporation. Our information, combined with SIR's, will provide the best possible framework to evaluate CO_2 storage economics and CO_2 storage performance, including long-term risks.

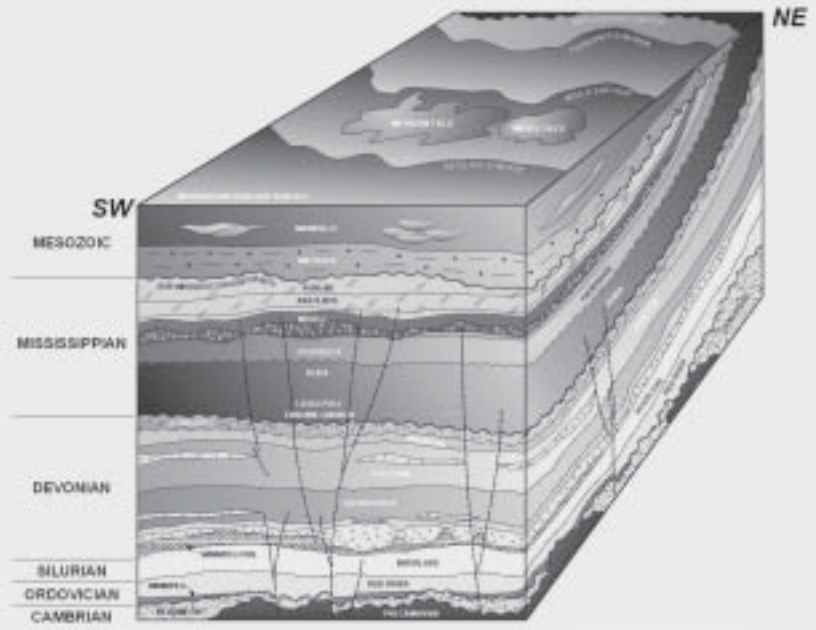

Figure 3. Three-dimensional block diagram showing a generalized version of the geologic framework of the Weyburn and Midale oil fields (amoeba like blobs on upper surface). Indications of the complexity of the geology include faults (subvertical bifurcating lines), unconformities (wavy sub-horizontal lines), thickness changes in salt beds (units with small plus signs), and the proximity of the oil fields to the regional Mesozoic unconformity (wavy line at base of Mesozoic boundary). Generalized age divisions are indicated on the left side of the diagram. Illustration reproduced courtesy of EnCana Oil Corporation.

Benefits

The benefits of this project for North Dakota are immediate and tangible. North Dakota benefits from the value added to lignite by selling the "waste" byproduct, CO_2, from the synfuels process. The CO_2 pipeline is in place and there is no doubt that the technique of miscible flooding of aging oil reservoirs in North Dakota with CO_2 will happen and that many additional millions of barrels of oil will be recovered.

More speculative perhaps is how the concept of CO_2 credits will play out. Some companies are currently trading them at prices from $2 to $10 per ton, but there is currently no formal CO_2 "bank," making this high risk speculation.

Many industries will need CO_2 credits if reduction of greenhouse gas becomes a global priority, and those capable of capturing and selling carbon dioxide will have a valuable product to sell whereas others may have to pay for disposal depending on their proximity to storage reservoirs.

North Dakota has many aging reservoirs in which to inject CO_2, which should substantially increase oil production and oil-related revenues for the state. CO_2 credits earned through geologic sequestration of CO_2 in such reservoirs may make it feasible for the coal industry to build additional coal-fired electricity-generating plants. New coal-fired power plants will require construction of new transmission lines, which in turn may benefit the blossoming wind-energy industry of North Dakota.

The process has tangible benefits for the world today, and there may be additional benefits in the future from CO_2 sequestration. Efficient use of natural resources is a goal all should strive to attain. Recycling our resources, carbon dioxide in this case, is part of efficient use of our resources and should be encouraged.

There are many facets to geologic sequestration of CO_2 and for its use in miscible flooding of Williston Basin oil reservoirs. Participation in this project is providing NDGS geologists with the knowledge necessary to advise the Industrial Commission as implementation of this technology proceeds in our State.

P.S. "...(This is) one of the grand challenges of the century," said Lynn Orr, a petroleum engineer at Stanford who will lead a new project that also will examine carbon sequestration. An international consortium of energy companies intends to pump $225 million over the next decade into the project.

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