SEQUESTRATION POTENTIAL OF PETROLEUM RESERVOIRS IN THE WILLISTON BASIN

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September 2005

EXECUTIVE SUMMARY

The Plains CO_2 Reduction (PCOR) Partnership region has significant potential for carbon sequestration. While the methods employed in this study look specifically at the potential sequestration capacity of oil fields within the Williston Basin, they can be used to determine reconnaissance-level sequestration capacity in any oil-producing region. Two methods have been utilized to estimate capacity, one based on oil pools undergoing enhanced oil recovery (EOR) and the other assuming that the reservoir pore space can be filled to capacity with carbon dioxide (CO_2). The focus of the work described in this paper is to broadly characterize the potential CO_2 sequestration capacity of Williston Basin oil fields.

This report will discuss the methods used and provide some general quantitative values in determining the sequestration capacity of selected Williston Basin oil fields. These fields have been chosen based on their cumulative production totals and are thought to possess the characteristics that will promote long-term storage of CO_2. The objective of this work is to develop a method that can be used to choose sites based not only on EOR potential, but also on the CO_2 volume that can be sequestered.

Absent non-market-based incentives, CO_2 sequestration in many geologic sinks is not generally economically viable under current market systems. However, EOR miscible flooding is a proven, economically viable technology for CO_2 sequestration that can provide a bridge to conducting non-EOR-based geologic sequestration. For example, a portion of the revenue generated by CO_2 EOR activities can pay for the infrastructure necessary for future geologic sequestration in brine formations. It is expected that unitized oil fields subjected to this type of recovery process should retain all of the injected gas (including the amount recycled during production) as a long-term storage solution. The process of CO_2 injection with respect to EOR has been engineered to reduce the amount of CO_2 needed for injection while maximizing incremental oil production. One approach to implementing geologic sequestration is to use the 30 years of experience injecting CO_2 into reservoirs in an effort to maximize CO_2 sequestration, with incremental

recovery becoming a benefit rather than the objective.

As production matures, those fields that have not yet been unitized and undergone EOR or are considered depleted and abandoned become prime candidates for CO_2 sequestration. Sequestration can be accomplished in these fields by initiating EOR with CO_2 miscible flooding or by simply considering the reservoir for storage and filling it to capacity. With approximately 1100 oil fields in the Williston Basin region of the PCOR Partnership, the potential CO_2 storage capacity is significant.

Based on the data available, North Dakota, Saskatchewan, and Manitoba unitized oil fields were chosen to study the potential incremental oil recovery and subsequent CO_2 storage capacity resulting from EOR. Of the unitized fields examined, the potential maximum storage value of CO_2, in billion cubic feet (Bcf), for each of these areas is listed here: North Dakota, 2095; Saskatchewan, 1515; and Manitoba, 319. This is equivalent to nearly 241 million tons of CO_2 when combined. A more complete table of selected fields in each of these areas is given in the text.

Fields were also looked at as potential storage areas for non-EOR-related CO_2 sequestration. The calculation is based largely on the pore volume of the reservoir that can be filled with CO_2. This gives a maximum storage potential for each field looked at in the study area. As a general reconnaissance, based on available data, oil pools in selected fields of North Dakota, Montana, and South Dakota were examined with the thought that the method could be applied to any reservoir with a competent top and bottom seal to get a rough estimate of storage capacity. To illustrate the potential, the cumulative yearly production of CO_2 from sources within a 150-mile radius centered at Dickinson, North Dakota, is approaching 45 million tons. The selected North Dakota pools (20) have the potential to hold approximately 2.1 billion tons of CO_2, based on the non-EOR CO_2 sequestration method. This volume represents approximately 47 years of the current cumulative CO_2 emissions from 25 source facilities.

ACKNOWLEDGMENTS

The PCOR Partnership is a collaborative effort of public and private sector stakeholders working toward a better understanding of the technical and economic feasibility of capturing and storing (sequestering) anthropogenic CO_2 emissions from stationary sources in the central interior of North America. It is one of seven regional partnerships funded by the U.S. Department of Energy's (DOE's) National Energy Technology Laboratory (NETL) Regional Carbon Sequestration Partnership (RCSP) Program. The Energy & Environmental Research Center (EERC) would like to thank the following partners who provided funding, data, guidance, and/or experience to support the PCOR Partnership:

- Alberta Department of Environment
- Alberta Energy and Utilities Board
- Alberta Energy Research Institute
- Amerada Hess Corporation
- Basin Electric Power Cooperative
- Bechtel Corporation
- Center for Energy and Economic Development (CEED)
- Chicago Climate Exchange
- Dakota Gasification Company
- Ducks Unlimited Canada
- Eagle Operating, Inc.
- Encore Acquisition Company
- Environment Canada
- Excelsior Energy Inc.
- Fischer Oil and Gas, Inc.
- Great Northern Power Development, LP
- Great River Energy
- Interstate Oil and Gas Compact Commission
- Kiewit Mining Group Inc.

- Lignite Energy Council
- Manitoba Hydro
- Minnesota Pollution Control Agency
- Minnesota Power
- Minnkota Power Cooperative, Inc.
- Montana–Dakota Utilities Co.
- Montana Department of Environmental Quality
- Montana Public Service Commission
- Murex Petroleum Corporation
- Nexant, Inc.
- North Dakota Department of Health
- North Dakota Geological Survey
- North Dakota Industrial Commission Lignite Research, Development and Marketing Program
- North Dakota Industrial Commission Oil and Gas Division
- North Dakota Natural Resources Trust
- North Dakota Petroleum Council
- North Dakota State University
- Otter Tail Power Company
- Petroleum Technology Research Centre
- Petroleum Technology Transfer Council
- Prairie Public Television
- Saskatchewan Industry and Resources
- SaskPower
- Tesoro Refinery (Mandan)
- University of Regina
- U.S. Department of Energy
- U.S. Geological Survey Northern Prairie Wildlife Research Center
- Western Governors' Association
- Xcel Energy

The EERC also acknowledges the following people who assisted in the review of this document:

Erin M. O'Leary, EERC
Edward C. Murphy, North Dakota Geological Survey
Steve G. Whittaker, Saskatchewan Industry and Resources
Kim M. Dickman, EERC
Stephanie L. Wolfe, EERC

BACKGROUND/INTRODUCTION

As one of seven Regional Carbon Sequestration Partnerships (RCSPs), the Plains CO_2 Reduction (PCOR) Partnership is working to identify cost-effective carbon dioxide (CO_2) sequestration systems for the PCOR Partnership region and, in future efforts, to facilitate and manage the demonstration and deployment of these technologies. In this phase of the project, the PCOR Partnership is characterizing the technical issues, enhancing the public's understanding of CO_2 sequestration, identifying the most promising opportunities for sequestration in the region, and detailing an action plan for the demonstration of regional CO_2 sequestration opportunities.

This report focuses on the sequestration potential of oil fields in the Williston Basin. Preliminary calculations, based on readily available data sources, were made to determine the quantity of CO_2 that could potentially be sequestered in pools that are currently in a distinct phase of production. For convenience, data were separated into those fields that are undergoing enhanced oil recovery (EOR) and those that are not. The process involved in making a determination of the characteristics that make specific geologic reservoirs within the PCOR Partnership region suitable for CO_2 sequestration is discussed in more detail in the following text.

The results of this report are based on the present status of oil production in the Williston Basin and primarily aims to provide insight into the method used to determine how much CO_2 can potentially be sequestered in geologic reservoirs. Tables found throughout this report have been compiled from the regional analysis and are generally a reflection of the pools that have significant potential to be considered for CO_2 sequestration.

SEQUESTRATION THROUGH EOR

Carbon sequestration through EOR is one of the first mechanisms to be used as a long-term strategy for reducing anthropogenic CO_2 from greenhouse gas emissions. The oil and gas industry has been involved in EOR through miscible CO_2 flooding for over 30 years. This knowledge has direct application to CO_2 sequestration. Based on rock and fluid properties, it has been estimated that about 80% of the oil reservoirs worldwide would be candidates for CO_2 injection (Kovscek, 2002). In response to this, the PCOR Partnership felt it was crucial to consider this aspect of carbon sequestration a priority.

As part of this study, it was necessary to perform a regional geologic characterization of many of the oil fields within the Williston Basin. This was accomplished by gathering data from readily available public sources collected at state agencies throughout the region. Immediately, it was found that the number of oil fields in the three states and two Canadian provinces of the Williston Basin would need to be pared down to a manageable number.

Since many of the opportunities for CO_2 sequestration in the Williston Basin are located in North Dakota, and the North Dakota PCOR Partnership partners afford us access to detailed data in North Dakota, much of this report deals with North Dakota oil fields. While production data were generally available, they were usually combined into cumulative field statistics. Future data collection efforts will need to split this into primary and secondary production to determine reservoir performance and response to recovery techniques. As an initial screening criteria, those fields with a current cumulative production of at least 800 thousand barrels of oil (MBO) were selected to collect reservoir data on and, in turn, determine a sequestration potential. For EOR, only those unitized fields that have gone through, or are currently in, a secondary recovery phase were considered. In general, secondary performance data are necessary to accurately predict tertiary performance.

Several data sources listing the reservoir characteristics for each state and Canadian province were compiled and combined into a large spreadsheet (one for each state and province). These spreadsheets include the key variables needed for evaluating the use of CO_2 EOR and additional rock and fluid properties necessary for determining geologic sequestration in depleted reservoirs. Because of the availability and ease of data collection with respect to the geologic parameters needed, North Dakota was used to illustrate both methods in this study. To give a general characterization of the region, each additional state and province throughout the Williston Basin is represented by one of two methods. Further study will begin to identify specific targets and determine whether a field is suitable for EOR or non-EOR CO_2 sequestration. This will include detailed production, reservoir, and geophysical analyses for identified targets.

A discussion follows of the process used for the identification and sequestration capacity of pools with suitable properties for carbon sequestration through EOR in North Dakota. The approach applied here is similar to that applied by Nelms and Burke (2004) in their evaluation of CO_2 EOR to North Dakota oil reservoirs. The procedures described in this report have been applied to each state and province (where applicable data were available) in the Williston Basin area of the PCOR Partnership region.

Methods Used for CO_2 Sequestration Capacity Through EOR

Data for North Dakota unitized oil pools were acquired from the North Dakota Industrial Commission's (NDIC's) Web site (www.oilgas.nd.gov). All units considered are at least in secondary recovery phase (water injection). The specific pools were selected through a joint meeting between the Energy & Environmental Research Center (EERC) and the North Dakota Oil and Gas Division and the North Dakota Geological Survey (NDGS) (two NDIC agencies) as being good candidates for CO_2 EOR. NDGS has been assessing all aspects of the CO_2 sequestration problem as a research provider for the International Energy Agency's (IEA's) Weyburn CO_2 Monitoring and Storage Project (Burke, 2003), including CO_2 injection for EOR to enhance production in the Williston Basin (Burke and Nelms, 2004a) which has been the emphasis of the Oil and Gas Division. Historically, this technique has been engineered to reduce the amount of CO_2 needed for injection while maximizing incremental oil production. The objective of the method employed herein is to maximize the volume of sequestration CO_2. This will be done using the knowledge gained from past and present CO_2 studies coupled with production and injection histories. The following list of reservoir and fluid properties was suggested by Bachu et al. (2004) and provides a simple guideline for screening reservoirs for CO_2 EOR:

- Oil gravity between 27° and 48° API
- Temperature between 90° and 250°F (32° and 121°C)
- Reservoir pressure greater than 1100 psi (77.3 kg/cm^2)
- Pressure greater by at least 200 psi (14 kg/cm^2) than the minimum miscibility pressure (1450–2175 psi [102–153 kg/cm^2])
- Oil saturation greater than 25%

This study considers these properties as well as the overall production history of the field, secondary recovery performance, depth to production, rock properties, and characteristics of the produced fluid. For example, the average temperatures and pressures across the basin will exceed these suggested values. For North Dakota, average reservoir temperature and pressure were found to be greater than 200°F (93°C) and 4000 psi (281 kg/cm^2), respectively.

In trying to determine the sequestration capacity for the unitized pools, some assumptions had to be made. The first major assumption was to simplify the process for projecting the oil recovery potential from injection of CO_2. Shaw and Bachu (2002) noted that the oil production increase could be anticipated to be between 7% and 23% of the original oil in place (OOIP) through successful miscible flooding techniques, while Nelms and Burke (2004) suggest a value of 7% to 11%. The spreadsheet used herein uses an average value of 12% recovery of the OOIP. Next, the quantity of CO_2 necessary to recover incremental oil was needed. Nelms and Burke (2004) discuss the quantity of CO_2 required for EOR. The purchase requirement they used was 13 thousand cubic feet (13 Mcf) per barrel of oil recovered. Of this purchase quantity, about 3 to 5 Mcf per barrel of oil will be recovered at the surface and reinjected after separation. This evaluation uses 8 Mcf per bbl incremental oil recovered. The total quantity of CO_2 injected for tertiary recovery should be the amount left in the reservoir for long-term storage. Postproduction treatment of the reservoir, such as blowdown, will need to be evaluated to determine the effect on the fate of CO_2 storage. Table 1 lists 28 unitized pools in North Dakota. It indicates the potential for EOR incremental oil recovery as well as volume of CO_2 that can be sequestered through the process.

The calculation is as follows:

$$Q = (OOIP) * (0.12) * (8000)$$

Where:
Q = CO_2 remaining in the reservoir after flooding process is complete, ft^3
OOIP = Original oil in place, stb
0.12 = Estimated recovery of oil from CO_2 flood, %
8000 = CO_2 purchase requirement to produce 1 barrel of oil from CO_2 flooding, ft^3

Currently, CO_2-based EOR is unrealized in North Dakota, with one obstacle being the economics of delivering CO_2 to the injection site (Burke and Nelms, 2004a). CO_2 flooding is under way at the Weyburn Field in Saskatchewan and appears to be successful in recovering significant amounts of incremental oil (Hassan, 2004).

With the progress of the research as part of the IEA Weyburn CO_2 Monitoring and Storage Project, the potential sequestration of CO_2 through the use of EOR techniques in the Williston Basin can be realized. The possibility of initiating CO_2 injection in the Williston Basin may come from the independent oil field operator interested in tertiary recovery from fields located close enough to the 200-mile stretch of pipeline between Beulah, North Dakota, and Weyburn, Saskatchewan. Figure 1 shows the proximity of the selected North Dakota unitized oil fields to the existing CO_2 pipeline.

Sequestration in Oil Reservoirs Not Currently Undergoing EOR

Carbon sequestration through EOR may be economically feasible in the near future if carbon storage credits become available and, in turn, will help develop the network of infrastructure necessary to transmit CO_2 throughout the Williston Basin. There are EOR operations in about 80 oil fields in North Dakota, primarily through waterflooding. This is about 15% of all the fields in the state, a number that will increase as more operators move to secondary recovery mechanisms. As production within the basin matures, some fields that have not yet been unitized and undergone EOR, or are considered

Table 1. North Dakota Unitized Pools and Their Potential for CO_2 EOR and CO_2 Storage Capacity (based on the amounts of OOIP)

NDIC Unit Name	NDIC Pool Unitized	NDIC Estimated OOIP, million stb	CO_2 Oil Recovery at 12% NDIC OOIP, million stb	CO_2 Needed Using 8 Mcf/bbl Oil Recovered, Bcf	Potential CO_2 Storage, Bcf	Potential CO_2 Storage, million tons
Cedar Hills South	Red River 'B'	360	43	346	346	21
Tioga	Madison	216	26	207	207	13
Beaver Lodge	Madison	172	21	165	165	10
Big Stick	Madison	166	20	159	159	10
Fryburg	Heath–Madison	155	19	149	149	9
Beaver Lodge	Devonian	139	17	133	133	8
Antelope	Madison	100	12	96	96	6
Newburg	Spearfish–Charles	96	12	92	92	6
Wiley	Glenburn	96	12	92	92	5
Blue Buttes	Madison	93	11	89	89	5
Charlson North	Madison	80	10	77	77	5
Rival	Madison	79	9	76	76	5
Dickinson	Heath	62	7	59	59	4
Medora	Heath–Madison	58	7	56	56	3
North Elkhorn Ranch	Madison	56	7	53	53	3
Beaver Lodge	Silurian	34	4	33	33	2
Lignite	Madison	33	4	31	31	2
Rough Rider East	Madison	31	4	30	30	2
Clear Creek	Madison	27	3	26	26	2
Fryburg South	Tyler	22	3	21	21	1
Knutson	Madison	19	2	18	18	1
Beaver Lodge	Ordovician	18	2	18	18	1
Antelope	Devonian	16	2	16	16	1
Mohall	Madison	15	2	15	15	1
Bear Creek	Duperow	14	2	13	13	1
Charlson South	Madison	10	1	9	9	1
Tracy Mountain	Tyler	9	1	9	9	0.5
Landa	Madison	8	1	8	8	0.5
Total Potential Storage in Selected Units					**2095**	**128**

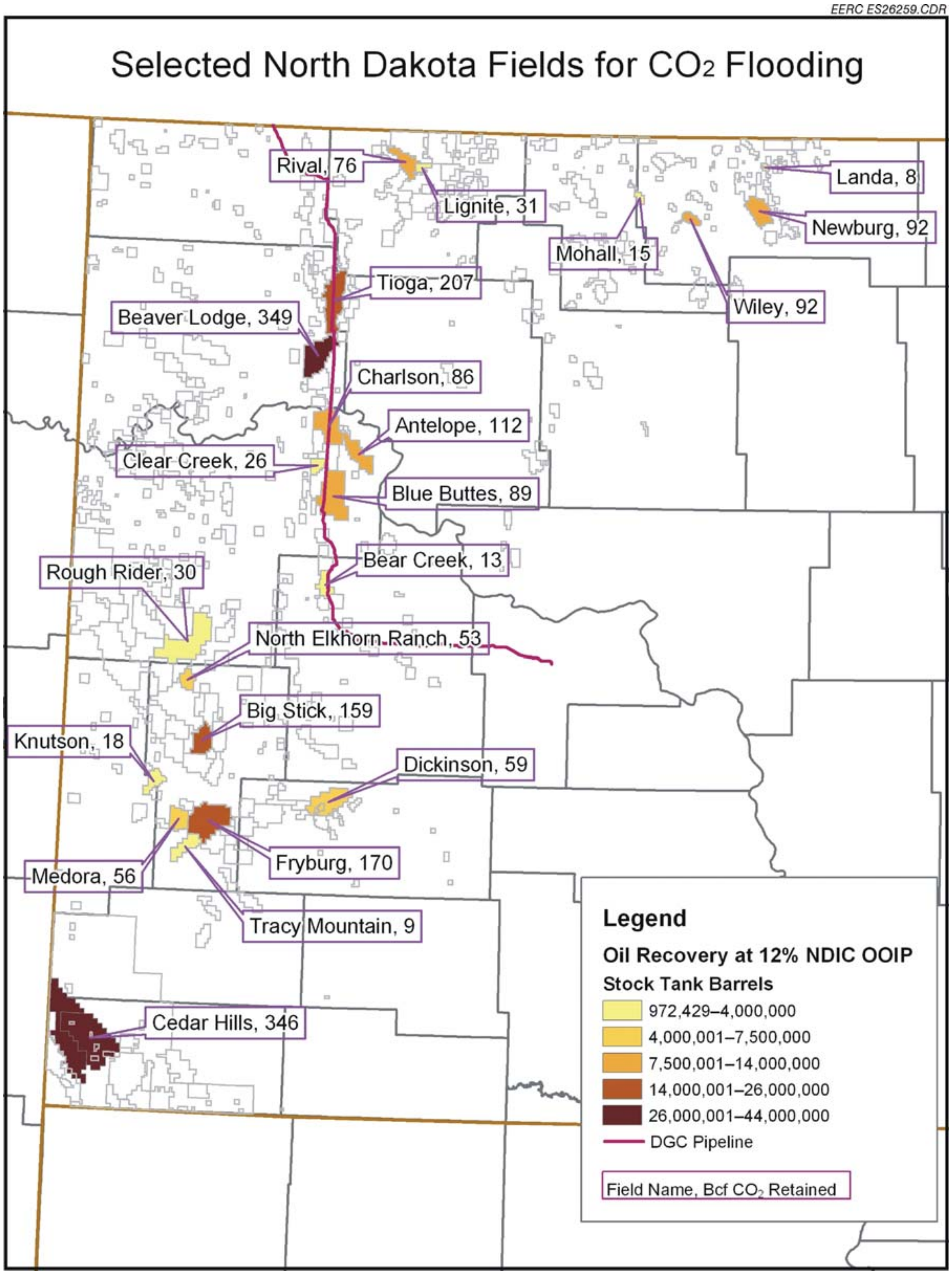

Figure 1. Selected North Dakota unitized oil fields and their potential EOR and sequestration capacity. This figure is based on the data presented in Table 1 and shows the proximity to the existing Dakota Gasification Company (DGC) CO_2 pipeline.

depleted and abandoned, may become candidates for CO_2 sequestration. Sequestration may be accomplished in the producing pools of some of these fields by initiating EOR with CO_2 miscible flooding or by considering the pool as a storage tank and filling it to capacity. The potential for sequestration continues to expand when the entire Williston Basin region and its approximately 1100 oil-producing fields are considered. While not the primary goal, injection into fields economically unsuitable for EOR can be engineered toward maximizing incremental oil production. Revenue from this could help offset the cost of CO_2 compression and transmission (Kovscek, 2002). The methods and criteria for determining the quantity of CO_2 that could be sequestered per oil field are described in the following section.

Methods Used for Geologic Sequestration Capacity in Currently Abandoned or Depleted Oil Fields

Using the same production criterion of 800 MBO (cumulative field production) that was used on the EOR pools, a detailed spreadsheet of geologic and fluid characteristics was developed for North Dakota.

Data for this spreadsheet were compiled from a number of sources, including Web-based data sets and data collection at state (Burke and Nelms, 2004b; www.state.nd.us/ndgs) and federal agencies. Each pool in a field appears as a unique entry in the database; some of these include unitized fields. This same procedure was used for pools in the Williston Basin region for which data were available prior to the writing of this paper. In calculating the sequestration capacity, the following criteria were used:

- Field surface area
- Average pay thickness
- Average porosity
- Reservoir temperature
- Initial reservoir pressure

Field area, thickness, and porosity were used to determine the pore volume of the producing reservoir. Reservoir temperature and pressure were used to determine the density of CO_2 at reservoir conditions. These temperature and pressure values were used to determine reservoir suitability for miscible flooding. Because there is significant variability in temperature and pressure throughout the oil-producing formations in North Dakota, the resulting sequestration values are to be viewed as a general reconnaissance.

The calculation is as follows:

$$Q = (A) * (T) * (\varphi) * (\rho_{CO2}) * (1 - S_w)$$

Where:
Q = Storage capacity of the oil reservoir, lb CO_2
A = Field area, ft^2
T = Producing interval thickness, ft
Φ = Average reservoir porosity, %
ρ_{CO2} = Density of CO_2, lb/ft^3
$(1 - S_w)$ = Saturation of oil, where S_W is the initial reservoir water saturation, %

This calculation yields the maximum storage capacity of an oil-bearing reservoir in pounds (lbs) of CO_2.

The major assumption made for these fields was that all of the fluid in the reservoir would be replaced with CO_2, effectively giving the maximum sequestration volume. While actual sequestration volumes will be significantly less, this means of developing approximate sequestration volumes has been used in prior studies (Bradshaw et al., 2004). With further study, a more detailed understanding of the exact sequestration capacity of the basin can be accomplished. A list of 20 fields selected on sequestration capacity is shown in Table 2; they are illustrated in Figure 2 relative to their proximity to the existing DGC pipeline.

Table 2. Selected North Dakota Oil Fields and Their Potential for CO_2 Sequestration[1]

Field Name	Producing Pool[2]			Est. CO_2 Capacity, million tons	Est. Sequestration Capacity, Bcf
	Group	Formation	Subformation		
Cedar Hills	Big Horn	Red River	“B”	576	9392
Little Knife	Big Horn	Red River	Nonspecific[3]	278	4531
Rough Rider	Jefferson	Duperow	Nonspecific	103	1678
Mondak	Big Horn	Red River	Nonspecific	102	1659
Beaver Lodge	Big Horn	Red River	Nonspecific	89	1448
Beaver Lodge	Madison	Lodgepole	Capa	83	1347
Rough Rider	Madison	Undesignated	Nonspecific	79	1296
Cedar Creek	Big Horn	Red River	Nonspecific	79	1287
Charlson	Madison	Undesignated	Nonspecific	74	1215
Rough Rider	Madison	Mission Canyon	Nesson	72	1177
Charlson	Jefferson	Birdbear/Duperow	Nonspecific	64	1044
Beaver Lodge	Madison	Undesignated	Nonspecific	64	1038
Charlson	Jefferson	BirdBear	Nisku	63	1025
Rocky Ridge	Minnelusa	Tyler	Heath	61	1001
Charlson	Nonspecific	Interlake	Nonspecific	60	978
Bicentennial	Madison	Mission Canyon	Nonspecific	58	938
Fryburg	Madison	Mission Canyon	Nonspecific	55	895
Mondak	Jefferson	Duperow	Nonspecific	50	809
Tioga	Madison	Undesignated	Nonspecific	49	800
Blue Buttes	Big Horn	Stonewall	Nonspecific	49	797
Total Potential Storage in Selected Pools				**2106**	**34,356**

[1] This table is a representation of the potential for sequestration in an entire field, assuming that 100% of the pore space will be filled with CO_2.

[2] Pool is a unit of production within a field. An oil field may consist of one or more pools.

[3] The authors have applied the term “nonspecific” to pools for which no subformation name was given in the available data.

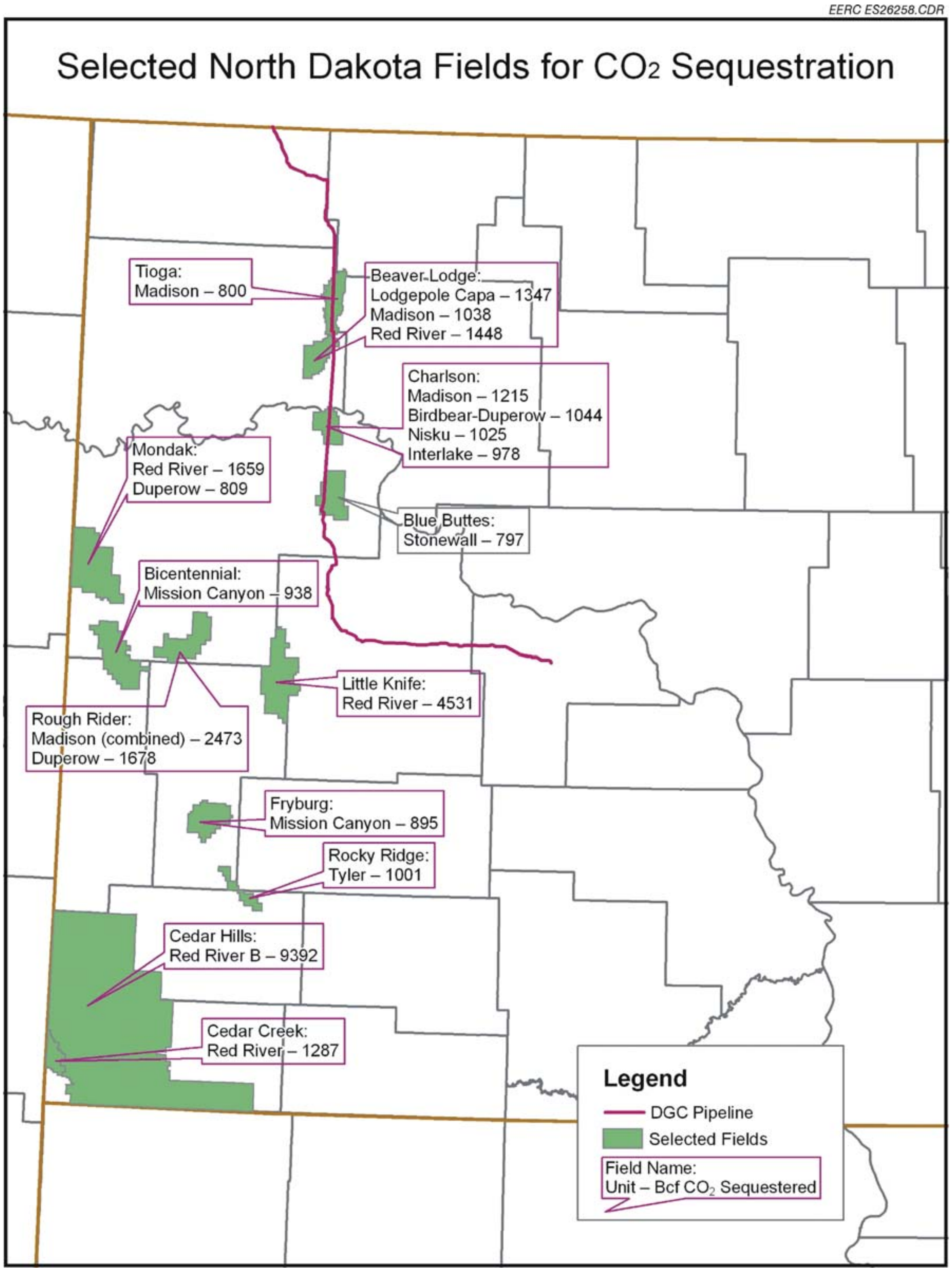

Figure 2. Selected North Dakota oil fields showing the estimated maximum CO_2 volume that can be sequestered. This is calculated using entire field area, thickness of the producing interval, porosity, and CO_2 density. The DGC pipeline is also shown.

WILLISTON BASIN REGION SEQUESTRATION CAPACITIES

As mentioned previously, the methods for determining sequestration capacities through EOR and geologic sequestration were used throughout the Williston Basin. These fields were chosen on their cumulative production histories and the geologic parameters that make them suitable for CO_2 storage. While fields throughout the region are in varying stages of recovery and are either unitized or nonunitized, the following sections provide examples of the methods used to determine sequestration capacities. As this project progresses, more detailed studies will be completed, and individual fields will be geologically and economically characterized to determine their potential for sequestration and EOR. A short explanation of the data presented for each additional state and Canadian province is presented below.

South Dakota

While several fields in South Dakota were considered, only the Buffalo Field was selected for this study. Cumulative production in the state is approaching 40 million barrels of oil (MMBO) from which nearly 30 MMBO comes from this field. With only the southern edge of the Williston Basin extending into South Dakota, most of the production occurs to the north. This does not lessen the opportunities for EOR and sequestration through CO_2 flooding in the area. The Buffalo Field is undergoing a high-pressure air injection flood (fireflood), which has increased production dramatically. Similar potential for increased production may be possible using CO_2, without the risk of damaging the reservoir. Table 3 shows the potential for CO_2 sequestration in the Buffalo Field. Because this field is under a fireflood method of tertiary recovery, a sequestration-only calculation was used that assumed all the available pore space would be filled with CO_2.

Montana

Cumulative production was used to choose fields for sequestration in Montana. While many of these fields are using waterflooding and other techniques as a tertiary recovery mechanism and, in turn, have been unitized, a sequestration-only calculation was used to determine the sequestration capacities. This was done because of data availability and ease of collection at the time of this study. Many of the reservoir characteristics necessary for the calculations were available on the nonunitized pools but not on the subsequent unitized pools. As demonstrated with the North Dakota examples, the two methods differ with respect to the variables needed to perform the calculation. Both methods can be applied in Montana; however, at the time of this study, the OOIP for the unitized pools had not been obtained. With more detailed studies, the characteristics for the units can be obtained and a figure for EOR potential given. It is clear with the current level of production and drilling activity that

Table 3. South Dakota Buffalo Field and Its Potential for CO_2 Sequestration[1]

Field Name	Producing Pool			Est. CO_2 Capacity, million tons	Est. Sequestration Capacity, Bcf
	Group	Formation	Subformation		
Buffalo	Big Horn	Red River	Nonspecific	69	1131

[1] This table is a representation of the potential for sequestration in an entire field, assuming that 100% of the pore space will be filled with CO_2.

Table 4. Montana Oil Fields and Their Potential for CO_2 Sequestration[1]

Field Name	Producing Pool			Est. CO_2 Capacity, million tons	Est. Sequestration Capacity, Bcf
	Group	Formation	Subformation		
Pine		Interlake	Nonspecific	184	2998
Kevin-Sunburst		Nisku/Madison/Sawtooth	Nonspecific	114	1856
Little Beaver East	Big Horn	Red River	Nonspecific	104	1700
Pine	Big Horn	Red River	Nonspecific	99	1608
Bell Creek		Cretaceous Muddy	Nonspecific	93	1511
Cabin Creek		Interlake	Nonspecific	75	1217
Poplar East	Madison	Madison	A, B, and C	72	1167
Little Beaver	Big Horn	Red River	Nonspecific	71	1154
Cabin Creek		Interlake	Horst Block	66	1074
Sioux Pass North		Mission Canyon, Nisku	Nonspecific	53	871
Poplar, East	Madison	Charles	B	52	850
Cabin Creek	Big Horn	Red River	Nonspecific	49	802
Dwyer	Big Horn	Red River	Nonspecific	46	742
Pennel		Interlake	Nonspecific	39	635
Cabin Creek	Madison	Madison	Mission Canyon	39	632
Cabin Creek		Interlake	East Block	38	620
Cabin Creek		Red River–Interlake	Nonspecific	37	606
Cabin Creek	Madison	Madison	Horst Block	36	588
Monarch		Interlake, Red River	Nonspecific	34	561
Pennel	Big Horn	Red River	Nonspecific	33	540
Total Potential Storage in Selected Pools				**1333**	**21,734**

[1] This table is a representation of the potential for sequestration in an entire field, assuming that 100% of the pore space will be filled with CO_2.

Table 5. Manitoba Unitized Pools and Their Potential for CO_2 EOR and CO_2 Storage Capacity (based on the listed percentages of the estimated OOIP)

Field Name	Formation	Unit	Original Oil in Place, million stb	CO_2 Oil Recovery at 12% OOIP, million stb	CO_2 Needed Using 8 Mcf/bbl Oil Recovered, Bcf	Potential CO_2 Storage, Bcf	Potential CO_2 Storage, million tons
Waskada	Lower Amaranth A	Combined Waskada Units	149	18	143	143	9
Pierson	Lower Amaranth – Mission Canyon 3b A	Combined Lower Amaranth Units	70	8	67	67	4
Daly	Lodgepole A	Combined Daly Units	110	13	106	106	6
Daly	Bakken A	Combined Kola Units	4	0.4	3	3	0.2
Total Potential Storage in Selected Units						**319**	**20**

Table 6. Selected Saskatchewan Unitized Pools and Their Potential for CO_2 EOR and CO_2 Storage Capacity (based on the amounts of estimated OOIP)

Field Name	Formation	Unit	Original Oil in Place, million stb	CO_2 Oil Recovery at 12% OOIP, million stb	CO_2 Needed Using 8 Mcf/bbl Oil Recovered, Bcf	Potential CO_2 Storage, Bcf	Potential CO_2 Storage, million tons
Steelman	Midale	Combined Midale Units	697	842	669	669	41
Midale	Midale	Combined Midale Units	538	65	516	516	32
Pinto	Midale	Combined Midale Units	124	15	119	119	7
Steelman	Frobisher	Combined Frobisher Units	113	14	109	109	7
Workman	Frobisher	Combined Frobisher Units	43	5	41	41	3
Midale	Frobisher	Combined Central Frobisher Units	38	5	37	37	2
Workman	Midale	Combined Midale Units	12	1	11	11	1
Pinto	Frobisher	Combined Frobisher Units	7	1	7	7	0.4
Tableland	Winnipegosis	Winnipegosis	4	0.5	4	4	0.2
Benson	Midale	Combined Midale Units	1	0.2	1	1	0.1
Total Potential Storage in Selected Units						**1515**	**93**

the Montana portion of the Williston Basin holds significant reserves. With the installation of the infrastructure for CO_2 transmission, the recovery of these reserves may become reality. Table 4 shows the selected Montana fields and their producing formations, with their approximate sequestration capacity.

Manitoba

Manitoba's CO_2 sequestration capacity is based on the OOIP figures for the best-producing unitized pools. The methodology used here is the same as on the North Dakota units. Table 5 shows the combined selected Manitoba unitized pools and their EOR and sequestration potentials.

Saskatchewan

CO_2 sequestration is being tested in Saskatchewan by the IEA Weyburn CO_2 Monitoring and Storage Project. It is estimated that approximately 22 million metric tons of CO_2 will be injected into the Mississippian Midale reservoir of the Weyburn Field. The result of injection will be the net storage of approximately 15 million metric tons when considering the combustion of the oil produced by the flood and the CO_2 produced in compression and transmission of CO_2 to the site (Whittaker, 2004). With this in mind, it was decided to look at several additional unitized oil fields that traverse the Saskatchewan portion of the Williston Basin to calculate their CO_2 sequestration potential. A general cross section across the Saskatchewan portion of the Williston Basin was chosen, and the larger fields were evaluated based on OOIP value. The method for the calculation remains the same as that used in the North Dakota study area.

Table 6 shows the quantities determined from the calculation and is based on data collected from the 2002 Reservoir Annual produced by Saskatchewan Energy and Mines (Reservoir Annual, 2002).

Key Issues to Consider

The volumes of potentially sequestered CO_2 determined here are general reconnaissance values. Actual sequestration volumes will be significantly smaller. To calculate a more exact sequestration capacity for a reservoir, a systematic analysis, including detailed geologic characterization, production history, and modeling efforts, is necessary. Detailed geologic and engineering characterization, including field studies and modeling on the level that is necessary prior to unitization and secondary recovery, is required. Specifically, a detailed production history, including updated OOIP, projected cumulative primary and cumulative secondary recovery, injection statistics, and produced-water chemistry must be obtained. In addition, from a regulatory and royalty standpoint, a detailed protocol regarding mineral value will need to be developed prior to permanent sequestration in abandoned fields and units. The protocol will include 1) value to mineral owners for produced fluid, 2) value to mineral owners for storage, 3) liability in ownership of sequestered CO_2, and 4) liability for leakage through preexisting properly and improperly abandoned well bores. These risk assessment and economic feasibility studies will need to be part of a thorough evaluation. Furthermore, CO_2 source proximity, availability, and industry support must be considered as crucial aspects to geologic sequestration.

CONCLUSION

Williston Basin oil reservoirs have significant potential for carbon sequestration. The storage capacity for the pools on which the nonunitized method was done is approximately 3.5 billion tons. This represents a capacity of 78 years of annual emissions from stationary sources throughout the Williston Basin.

Screening criteria for field candidates were based on primary recovery of the oil reservoir. Fields that have been unitized and initiated a secondary phase of recovery are considered good candidates for CO_2 sequestration through EOR. It is expected that all of the injected gas will remain in the reservoir for long-term storage when tertiary recovery ends. The remaining nonunitized fields may be excellent candidates for additional storage and could potentially have the fluid in the pore space replaced by CO_2, with revenue from any incremental oil recovery helping to offset the cost of injection.

North Dakota, Saskatchewan, and Manitoba unitized oil field data were available to study the potential incremental oil recovery and subsequent CO_2 storage capacity resulting from EOR. The remaining states were looked at for storage after tertiary recovery ends. Table 7 illustrates the cumulative potential sequestration values for the selected fields referred to in the text. As mentioned previously, these general estimates illustrate the methods used in the calculation. With further study, a much more detailed approximation of sequestration capacity can be attained.

Table 7. Cumulative Totals from Previous Tables Showing the Method Used and the Conversion from Bcf to Metric Tons

Cumulative Total for Selected Fields	CO_2 Retention Potential, Bcf, nonunitized method	CO_2 Retention Potential, million tons, nonunitized method	CO_2 Retention Potential, Bcf, unitized method	CO_2 Retention Potential, million tons, unitized method
North Dakota	34,356	2106	2095	128
South Dakota	1131	69		
Montana	21,734	1333		
Manitoba			319	19
Saskatchewan			1515	93

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