BASIN ORIENTED STRATEGIES FOR CO$_2$ ENHANCED OIL RECOVERY:

ILLINOIS

Prepared for:
U.S. Department of Energy
Office of Fossil Energy – Office of Oil and Natural Gas

Prepared by:
Advanced Resources International, Inc.

March 2005

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1. SUMMARY OF FINDINGS

1.1 INTRODUCTION. The oil and gas producing region of Illinois has nearly 6 billion barrels of oil which will be left in the ground, or "stranded", following the use of today's oil recovery practices. A major portion of this "stranded oil" is in reservoirs technically and economically amenable to enhanced oil recovery (EOR) using carbon dioxide (CO_2) injection.

This report evaluates the future oil recovery potential in the large oil fields of Illinois and the barriers that stand in the way of realizing this potential. The report then discusses how a concerted set of "basin-oriented strategies" could help the region's oil production industry overcome these barriers.

1.2 ALTERNATIVE OIL RECOVERY STRATEGIES AND SCENARIOS. The report sets forth four scenarios for using CO_2-EOR to recover "stranded oil" from the major oil reservoirs of Illinois.

- The first scenario captures how CO_2-EOR technology has been applied and has performed in the past. This low technology, high-risk scenario, called "Traditional Practices" because of low oil recovery efficiency, is evaluated using a high risk (25%, before tax, real) rate of return.

- The second scenario, entitled "State of the Art", assumes that technology progress in CO_2-EOR, achieved in other areas, is successfully applied to the oil reservoirs of Illinois. In addition, a comprehensive set of fundamental research, pilot tests and field demonstrations (collectively called "basin opening" actions) help lower the risk (15% before tax, real) inherent in applying new technology to the complex oil reservoirs of Illinois. However, because of limited sources of CO_2, the CO_2 supply costs are high (equal to $1.25 per Mcf) and significantly hamper economic feasibility of using CO_2-EOR.

- The third scenario, entitled “Risk Mitigation,” examines how the economic potential of CO_2-EOR could be increased through a strategy of increased federal investment tax credits and royalty relief that together would provide an equivalent of a $10 per barrel increase in the WTI price for crude oil. (Illinois does not have a severance tax on oil production.)

- In the final scenario, entitled “Ample Supplies of CO_2,” the study assumes that low-cost, “EOR-ready” CO_2 supplies (equal to $0.70 per Mcf) are aggregated from various sources and delivered at pressure to oil fields. In the near-term, these CO_2 supplies could be from industrial high-concentration CO_2 emissions from hydrogen facilities, gas processing plants and other sources. These supplies would be augmented, in the longer-term, from low CO_2 concentration industrial sources including combustion and electric generation plants. Capture of industrial CO_2 emissions could be part of national efforts for reducing greenhouse gas emissions.

The CO_2-EOR potential of Illinois is examined using these four bounding scenarios.

***1.3 OVERVIEW OF FINDINGS*. Ten major findings emerge from the study of “Basin Oriented Strategies for CO_2 Enhanced Oil Recovery: Illinois.”**

1. Today’s oil recovery practices will leave behind a large resource of “stranded oil” in Illinois. The original oil resource in Illinois reservoirs was 9.4 billion barrels. To date, 3.7 billion barrels of this original oil in-place (OOIP) has been recovered or proved. Thus, without further oil recovery methods, 5.7 billion barrels of Illinois’ oil resource will become “stranded”, Table 1.

Table 1. Size and Distribution of Illinois Large Oil Reservoirs Data Base

Region	No. of Reservoirs	OOIP (Billion Bbls)	Cumulative Recovery/ Reserves (Billion Bbls)	ROIP (Billion Bbls)
A. Major Oil Reservoirs				
Illinois	65	6.4	2.5	3.9
B. Regional Total	n/a	9.4	3.7	5.7

2. A substantial portion of the "stranded oil" resource in the large oil reservoirs of Illinois is amenable to CO_2 enhanced oil recovery. To address the "stranded oil" issue, Advanced Resources assembled a database that contains 65 large Illinois oil reservoirs, accounting for 68.7% of the region's estimated ultimate oil production. Of these, 46 reservoirs, with 3.1 billion barrels of OOIP and 1.9 billion barrels of "stranded oil" (ROIP), were found to be favorable for CO_2-EOR, Table 2.

Table 2. Illinois "Stranded Oil" Amenable to CO_2-EOR

Region	No. of Reservoirs	OOIP (Billion Bbls)	Cumulative Recovery/ Reserves (Billion Bbls)	ROIP (Billion Bbls)
Illinois	46	3.1	1.2	1.9

3. Application "State of the Art" of CO_2-EOR would enable a significant portion of Illinois' "stranded oil" to be recovered. Of the 46 Illinois oil reservoirs favorable for CO_2-EOR, 16 reservoirs (1.4 billion barrels OOIP) screen as being favorable for miscible CO_2-EOR. The remaining 30 reservoirs (with 1.8 billion barrels OOIP) screen as being favorable for immiscible CO_2-EOR The total technically recoverable resource from applying CO_2-EOR in these 46 large oil reservoirs, ranges from 130 million barrels to 490 million barrels, depending on the type of CO_2-EOR technology that is applied - - "Traditional Practices" or "State of the Art", Table 3.

Table 3. Technically Recoverable Resource Using Miscible and Immiscible CO_2-EOR

	Miscible CO_2-EOR		Immiscible CO_2-EOR	
Region	No. of Reservoirs	Technically Recoverable* (MMBbls)	No. of Reservoirs	Technically Recoverable* (MMBbls)
Illinois	16	130 – 300	30	0-190

**Range in technically recoverable oil reflects the performance of "Traditional Practices" and "State of the Art" CO_2-EOR technology.*

4. With "Traditional Practices" CO_2 flooding technology, high CO_2 costs and high risks, none of Illinois' "stranded oil" is economically recoverable. Traditional application of miscible CO_2-EOR technology to the 16 large reservoirs in the data base would enable 130 million barrels of "stranded oil" to become technically recoverable from the region. However, with the current high costs for CO_2 ($1.25 per Mcf) plus uncertainties about future oil prices and the performance of CO_2-EOR technology, none of this "stranded oil" would become economically recoverable, Table 4.

Table 4. Economically Recoverable Resources Under Scenario #1: "Traditional Practices" CO_2-EOR

Basin	No. of Reservoirs	OOIP (MMBbls)	Technically Recoverable (MMBbls)	Economically* Recoverable (MMBbls)
Illinois	16	1,360	130	0

**This case assumes an oil price of $25 per barrel, a CO_2 cost of 5% of the oil price, and a ROR hurdle rate of 25% (before tax).*
***Less than 5 MMBbls.*

5. Introduction of "State of the Art" CO_2-EOR technology, "risk mitigation" actions, and lower CO2 costs would enable up to 470 million barrels of "stranded oil" to become economically recoverable. With "State of the Art" CO_2-EOR technology and its higher oil recovery efficiency, 370 million barrels of oil remaining in Illinois' reservoirs becomes economically recoverable. Risk mitigation actions, involving an increased EOR investment tax credit and Federal/state royalty relief (for projects on Federal or state lands) that together provide an equivalent of a $10 per barrel increase in this oil price, and lower cost CO_2 supplies (from a large transportation system and incentives for CO_2 capture) would enable 470 million barrels of oil to become economically recoverable from Illinois' large oil reservoirs, Figure 1 and Table 5.

Table 5. Economically Recoverable Resources Under Alternative Scenarios

	Scenario #2: "State of the Art"	Scenario #3: "Risk Mitigation"	Scenario #4: "Ample Supplies of CO_2"
State	(Moderate Oil Price/ High CO_2 Cost*) (MMBbls)	(Higher Equivalent Oil Price/ High CO_2 Cost**) (MMBbls)	(Higher Equivalent Price/ Low CO_2 Cost***) (MMBbls)
Illinois	370	470	470

**This case assumes an oil price of \$25 per barrel, a CO_2 cost of \$1.25 and a ROR hurdle rate of 15% (before tax).*
***This case assumes an oil price of \$35 per barrel, a CO_2 cost of \$1.25 and a ROR hurdle rate of 15% (before tax).*
****This case assumes an oil price of \$35 per barrel, a CO_2 cost of \$0.70 and a ROR hurdle rate of 15% (before tax).*

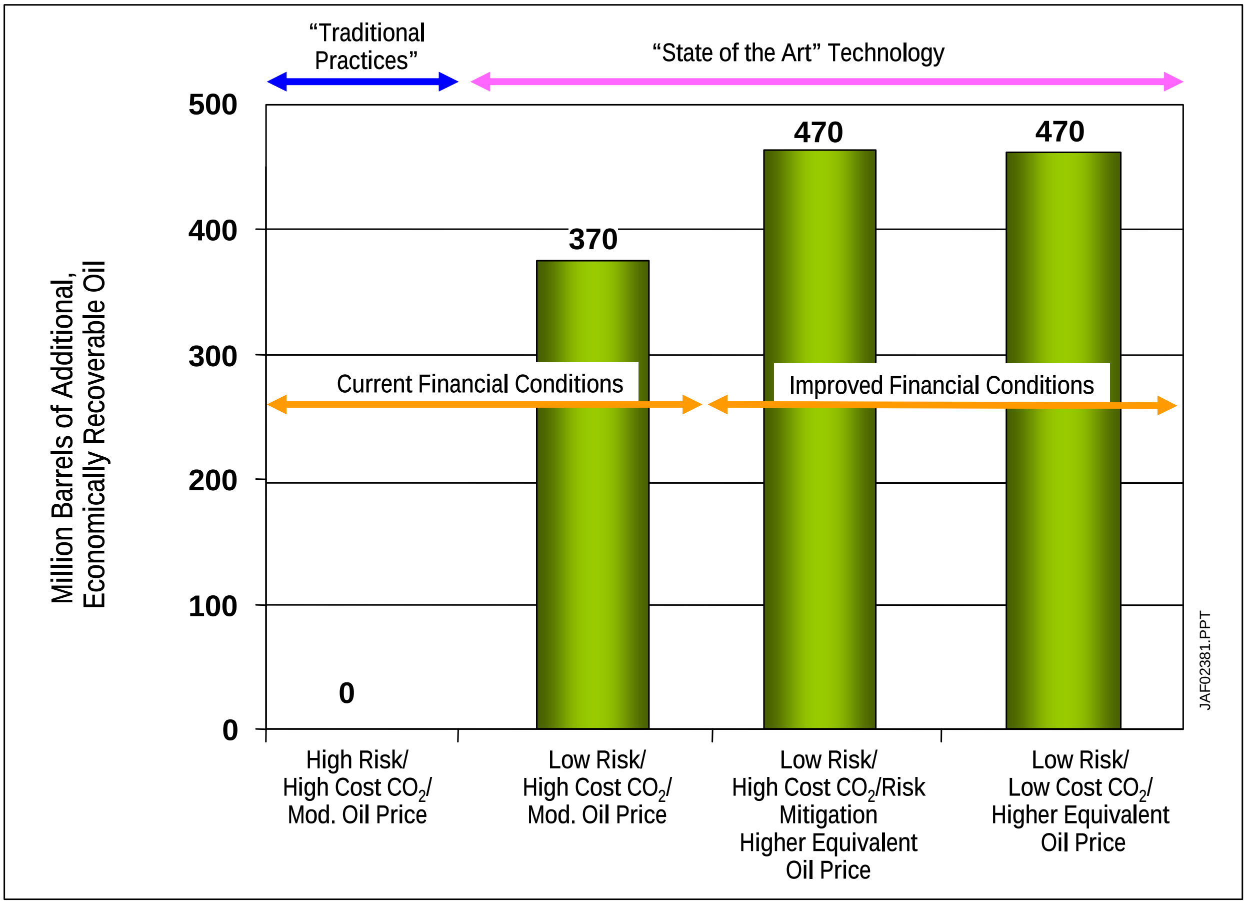


Figure 1. Impact of Improved Technology and Financial Conditions on Economically Recoverable Oil from Illinois' Major Reservoirs Using CO_2-EOR (Million Barrels).

6. Once the results from the study's large oil reservoirs database are extrapolated to the state as a whole, the technically recoverable CO_2-EOR potential for Illinois is estimated at 710 million barrels. The large Illinois oil reservoirs examined by the study account for 68.7% of the region's oil resource. Extrapolating the 490 million barrels of technically recoverable EOR potential in these 46 oil reservoirs to the total Illinois oil resource provides an estimate of 710 million barrels of technical CO_2-EOR potential. (However, no extrapolation of overall economic potential has been estimated, as the development costs of the 46 large Illinois oil fields may not reflect the development costs for the smaller oil reservoirs in the region.)

7. The ultimate additional oil recovery potential from applying CO_2-EOR in Illinois will, most likely, prove to be higher than defined by this study. Introduction of more "advanced" CO_2-EOR technologies still in the research or field demonstration stage, such as gravity stable CO_2 injection, extensive use of horizontal or multi-lateral wells and CO_2 miscibility control agents, could significantly increase recoverable oil volumes while expanding the state's geologic storage capacity for CO_2 emissions. The benefits and impacts of using "advanced" CO_2-EOR technology on Illinois oil reservoirs will be examined in a subsequent study.

8. Large volumes of CO_2 supplies will be required in Illinois to achieve the CO_2-EOR potential defined by this study. The overall market for purchased CO_2 could be up to 1.7 Tcf, plus another 3.5 Tcf of recycled CO_2, Table 6. Assuming that the volume of CO_2 stored equals the volume of CO_2 purchased and that the bulk of purchased CO_2 is from industrial sources, applying CO_2-EOR to Illinois' oil reservoirs would enable nearly 100 million tons of CO_2 emissions to be stored, greatly reducing greenhouse gas emissions. Advanced CO_2-EOR flooding and CO_2 storage concepts (plus incentives for storing CO_2) could double this amount.

Table 6. Potential CO_2 Supply Requirements in Illinois
Scenario #4 ("Ample Supplies of CO_2")

Region	No. of Reservoirs	Economically Recoverable* (MMBbls)	Purchased CO_2 (Bcf)	Recycled CO_2 (Bcf)
Illinois	39	470	1,690	3,470

**Under Scenario #4: "Ample Supplies of CO_2"*

9. A public-private partnership will be required to overcome the many barriers facing large scale application of CO_2-EOR in Illinois' oil fields. The challenging nature of the current barriers - - lack of sufficient, low-cost CO_2 supplies, uncertainties as to how the technology will perform in Illinois' oil fields, and the considerable market and oil price risk - - all argue that a partnership involving the oil production industry, potential CO_2 suppliers and transporters, the Illinois State Government and the Federal Government will be needed to overcome these barriers.

10. Many entities will share in the benefits of increased CO_2-EOR based oil production in Illinois. Successful introduction and wide-scale use of CO_2-EOR in Illinois will stimulate increased economic activity, provide new higher paying jobs, and lead to higher tax revenues for the state. It will help bolster a declining domestic oil production and service industry.

1.4 ACKNOWLEDGEMENTS. Advanced Resources would like to acknowledge the most valuable assistance provided to the study by a series of individuals and organizations in Illinois. We would like to thank the Illinois Geologic Survey, Oil and Gas Division, particularly Ms. Beverly Seyler, Mr. Scott Frailey and Mr. Brian Huff, for providing detailed historical oil production and well data for the oil producing fields within the state as well as allowing ARI advanced access to the Oil and Gas Division's waterflood database. This information was instrumental in allowing ARI to determine the breakout of producing to injecting wells for each oil reservoir within the state.

2. INTRODUCTION

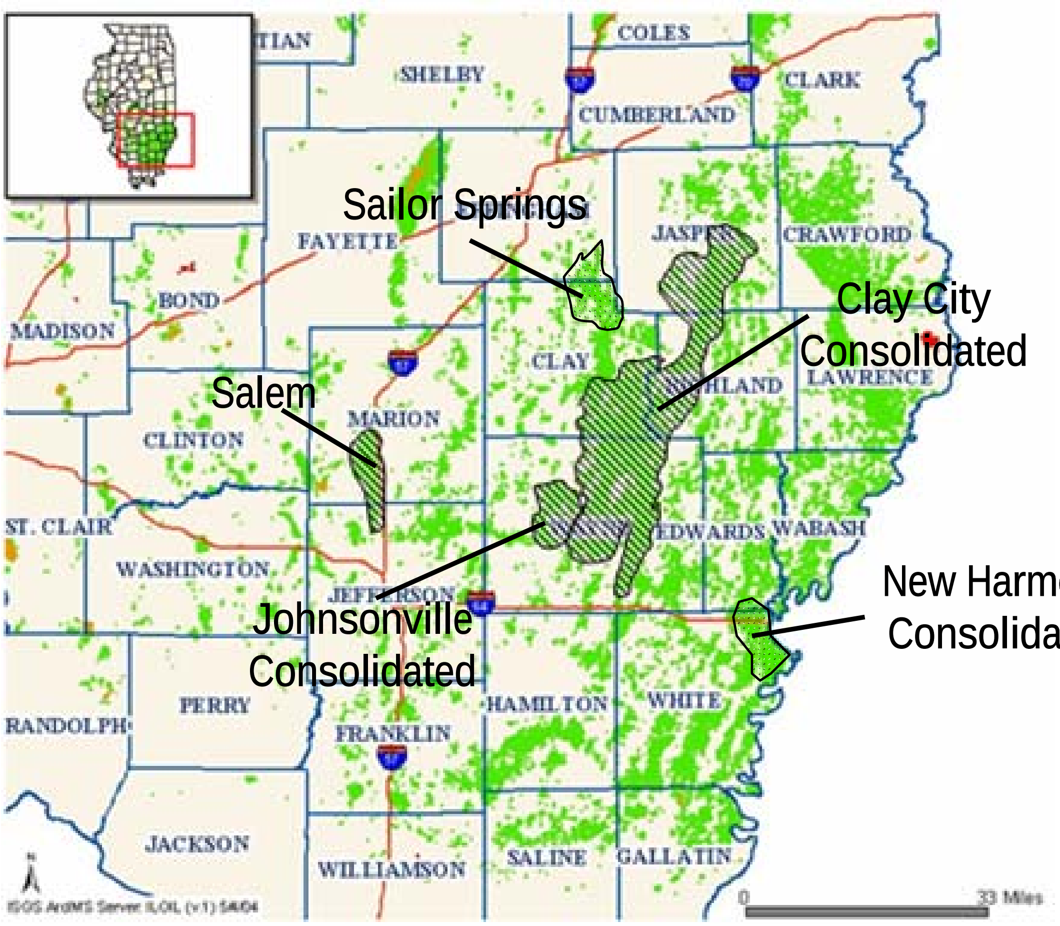
2.1 CURRENT SITUATION. Oil production in Illinois is from highly mature fields that are in decline. Arresting the decline in oil production will be a major challenge, requiring a coordinated set of actions by numerous parties who have a stake in this problem - - Illinois state revenue and economic development officials; private, state and Federal royalty owners; the Midwest oil production and refining industry; the public, and the Federal Government.

The main purpose of this report is to provide information to these “stakeholders” on the potential for pursuing CO_2 enhanced oil recovery (CO_2-EOR) as one option for slowing or potentially stopping the decline in Illinois’ oil production.

This report, “Basin Oriented Strategies for CO_2 Enhanced Oil Recovery: Illinois,” provides information on the size of the technical and economic potential for CO_2-EOR in the state of Illinois. It also identifies the many barriers - - insufficient and costly CO_2 supplies, high market and economic risks, and concerns over technology performance - - that currently impede the cost-effective application of CO_2-EOR in this Midwestern region.

2.2 BACKGROUND. In 2002, Illinois produced 25 thousand barrels of oil per day. The large, deeper, light oil reservoirs of this region are ideal candidates for miscible carbon-dioxide based enhanced oil recovery (CO_2-EOR). However, a great number of Illinois’ oil reservoirs are not sufficiently deep for CO_2-EOR. Application of miscible and immiscible CO_2-EOR technology could help oil production remain relatively steady for some time. Illinois’ oil producing region and the concentration of its major oil fields are shown in Figure 2.

Figure 2. Location of Major Illinois Oil Fields



2.3 PURPOSE. This report, “Basin Oriented Strategies for CO_2 Enhanced Oil Recovery: Illinois” is part of a larger effort to examine the enhanced oil recovery and CO_2 storage potential in key U.S. oil basins. Previous reports addressed the oil fields of California, Oklahoma, the Gulf Coast, and Alaska. The work involves establishing the geological and reservoir characteristics of the major oil fields in the region; examining the available CO_2 sources, volumes and costs; calculating oil recovery and CO_2 storage capacity; and, estimating economic feasibility.

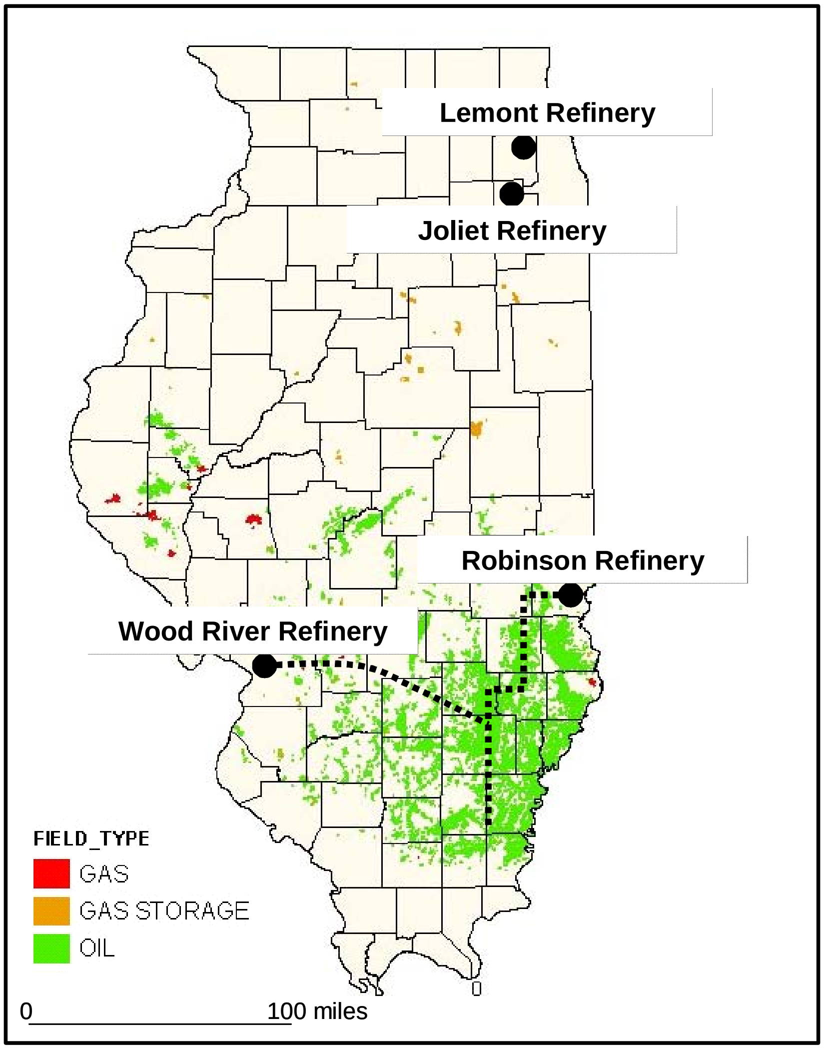
Future studies will also examine: 1) alternative public-private partnership strategies for developing lower-cost CO_2 capture technology; 2) launching R&D/pilot projects of advanced CO_2 flooding technology; and 3) structuring royalty/tax incentives and policies that would help accelerate the application of CO_2-EOR and CO_2 storage in the major oil basins of the U.S.

An important purpose of the larger study is to develop a desktop modeling and analytical capability for “basin oriented strategies” that would enable DOE/FE to formulate policies and research programs that would support increased recovery of domestic oil resources. As such, this desktop model complements, but does not duplicate, the more extensive TORIS modeling system maintained by DOE/FE’s National Energy Technology Laboratory.

2.4 KEY ASSUMPTIONS. For purposes of this study, it is assumed that sufficient supplies of CO_2 will become available, either by pipeline from natural sources, from industrial sources such as the refineries in Wood River and Robinson, Illinois, from power plants in the region, or from hydrogen plants like those at Wood River (hydrogen capacity of 57 MMcfd) and in Indiana (hydrogen capacity of 31 MMcfd). The timing of this availability assumes that CO_2 will be delivered in near future, as forecasting field life is not an aspect of this study. It may also be possible to obtain anthropogenic CO_2 from cement, fertilizer, and ethanol plants depending on their proximity to a field project.

Figure 3 provides a conceptual illustration of a CO_2 pipeline system that would transport captured CO_2 emissions from the ConocoPhillips’ Wood River and Marathon’s Robinson refinery to the oil fields of southern Illinois and makes no warranties as to the availability of pipeline right-of-ways due to environmental and/or landowner constraints.

Figure 3. Conceptual CO2 Pipeline System Connecting CO2 Sources With Illinois Oil Fields



2.5 TECHNICAL OBJECTIVES. The objectives of this study are to examine the technical and the economic potential of applying CO_2-EOR in Illinois oil region, under two technology options:

1. *"Traditional Practices" Technology*. This involves the continued use of past CO_2 flooding and reservoir selection practices. It is distinguished by using miscible CO_2-EOR technology in light oil reservoirs and by injecting moderate volumes of CO_2, on the order of 0.4 hydrocarbon pore volumes (HCPV), into these reservoirs. (Immiscible CO_2 is not included in the "Traditional Practices"

technology option). Given the still limited application of CO_2-EOR in this region and the inherent technical and geologic risks, economic evaluations typically add o risk factor for using this technology option in Illinois.

2. *"State of the Art" Technology*. This involves bringing to Illinois the benefits of recent gains in understanding of the CO_2-EOR process and how best to customize its application to the many different types of oil reservoirs in the region. As further discussed below, moderately deep, light oil reservoirs are selected for miscible CO_2-EOR and the shallower light oil and the heavier oil reservoirs are targeted for immiscible CO_2-EOR. "State of the Art" technology entails injecting much larger volumes of CO_2, on the order of 1 HCPV, with considerable CO_2 recycling.

   Under "State of the Art" technology, with CO_2 injection volumes more than twice as large, oil recovery is projected to be higher than reported for past field projects using "Traditional Practices", although this concept required further testing. The CO_2 injection/oil recovery ratio may also be higher under this technology option, further spotlighting the importance of lower cost CO_2 supplies. With the benefits of field pilots and pre-commercial field demonstrations, the risk premium for this technology option and scenario would be reduced to conventional levels.

The set of oil reservoirs to which CO_2-EOR would be applied fall into two groups, as set forth below:

1. *Favorable Light Oil Reservoirs Meeting Stringent CO_2 Miscible Flooding Criteria*. These are the moderately deep, higher gravity oil reservoirs where CO_2 becomes miscible (after extraction of light hydrocarbon components into the CO_2 phase) with the oil remaining in the reservoir. In Illinois, reservoirs at depths greater than 2,000 feet and with oil gravities greater than 25^o API would be considered for miscible CO_2-EOR (The great bulk of these reservoirs have light oil with gravities greater than 35° API). Major Illinois

light oil fields such as Clay City, Johnsonville and Salem fit into this category. The great bulk of past CO_2-EOR floods have been conducted in these types of “favorable reservoirs”.

2. *Challenging Reservoirs Involving Immiscible Application of CO_2-EOR*. Crude oil in Illinois is typically light (API > 25). As such, many of the reservoirs screened meet criteria for immiscible CO_2-EOR flooding. In addition, many of the large, shallow, light oil reservoirs may be candidates for “next generation” CO_2-EOR practices, including the use of miscibility extenders and gravity stable flooding.

Combining the technology and oil reservoir options, the following oil reservoir and CO_2 flooding technology matching is applied to Illinois’ reservoirs amenable to CO_2-EOR, Table 6.

Table 6. Matching of CO_2-EOR Technology With the Illinois’ Oil Reservoirs

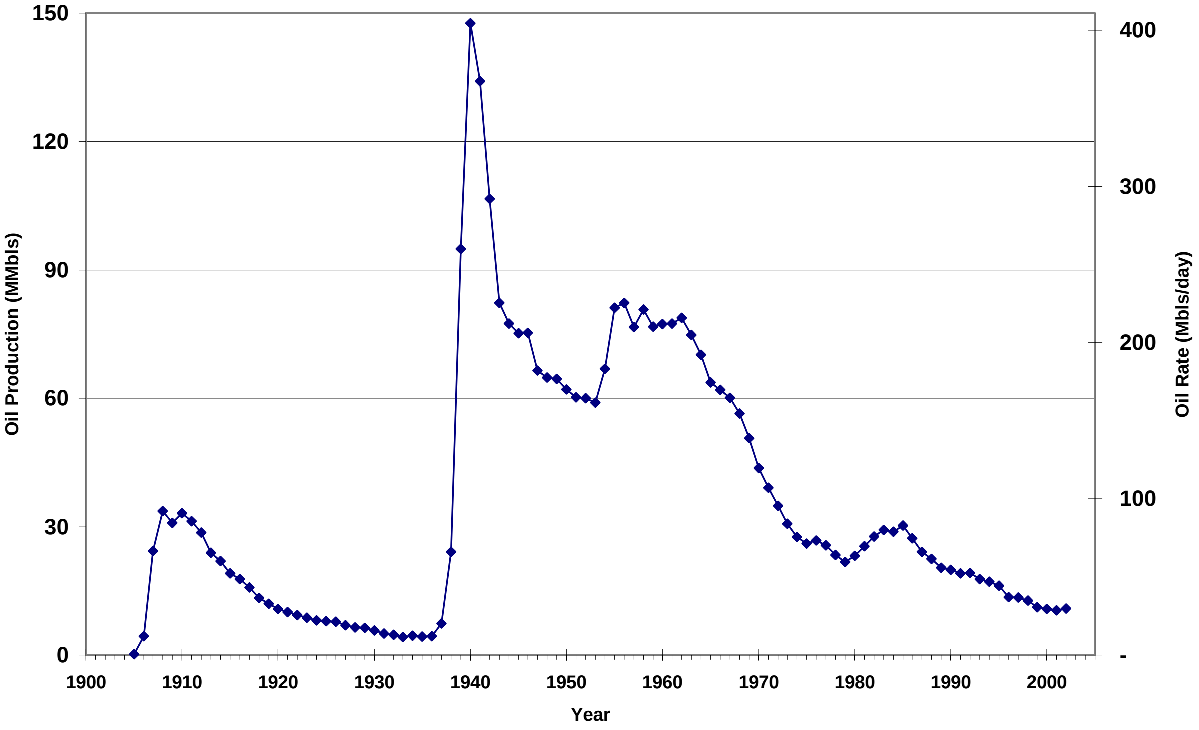
CO_2-EOR Technology Selection	Oil Reservoir Selection
“Traditional Practices”; Miscible CO_2-EOR	▪ Deep, Light Oil Reservoirs
“State of the Art”; Miscible and Immiscible CO_2-EOR	▪ Deep, Light Oil Reservoirs ▪ Deep, Moderately Heavy Oil Reservoirs

2.6 OTHER ISSUES. This study draws on a series of sources for basic data on the reservoir properties and the expected technical and economic performance of CO_2-EOR in the major oil reservoirs in Illinois. As such, reservoir-level data and results are not provided and are not available for general distribution. However, selected non-confidential and non-proprietary information at the field and reservoir level is provided in the report and additional information could be made available for review, on a case by case basis, to provide an improved context for the state and district level reporting of results in this study.

3. OVERVIEW OF ILLINOIS OIL PRODUCTION

3.1 HISTORY OF OIL PRODUCTION. Oil production in Illinois has experienced several rejuvenations over the past century, Figure 5. The advent of seismic surveying technique in the 1930s- and 40s rekindled exploration in Illinois and led to a high of 400 thousand barrels per day in 1941. Hydraulic fracturing and waterflooding technologies allowed production to expand again in the 1950s. Since this time, however, oil production has dropped steadily. Production in 2002 was down to approximately 30 thousand barrels of oil per day.

Figure 4. History of Illinois Oil Production, 1905-2002



Illinois still holds significant resource of oil in the ground. With 9.4 billion barrels of original oil in-place (OOIP) and approximately 3.7 billion barrels expected to be recovered, 5.7 billion barrels of oil will be "stranded" due to lack of technology, lack of sufficient, affordable CO_2 supplies and high economic and technical risk.

Table 7 presents the status and annual oil production for the five largest Illinois oil fields that account for 45% of the oil production in the state. The table shows that three of the largest oil fields are in production decline. Arresting this decline in Illinois' oil production could be attained by applying enhanced oil recovery technology, particularly CO_2-EOR.

Table 7. Crude Oil Annual Production, Five Largest Illinois Oil Fields, 1998-2000
(Million Barrels per Year)

Major Oil Fields	1998	1999	2000	Production Status
Lawrence County Division	1.5	1.4	1.3	Declining
Louden	0.8	0.6	0.4	Declining
Salem Consolidated	0.7	0.8	0.7	Stable
Clay City Consolidated	1.0	1.1	1.2	Increasing
Main Consolidated	1.1	1.0	0.9	Declining

3.2 EXPERIENCE WITH IMPROVED OIL RECOVERY. Illinois oil producers are familiar with using technology for improving oil recovery. For example, waterflooding techniques have been applied in the Illinois basin since the 1950s. By the end of 1985, over 100 reservoirs in more than 160 fields had undergone waterflooding.

Several waterflood projects have recovered significant volumes of oil. The Cypress formation in the Louden field has recovered more than 185 million barrels. It uses 748 injectors and 1,070 producing wells. The 64 injection wells in the Aux Vases formation of the Johnsonville field have injected more than 150 million barrels water. This has produced over 11 million barrels of oil.

3.3 THE "STRANDED OIL" PRIZE. Even though Illinois' oil production is declining, this does not mean that the resource base is depleted. For example, over 60% of its OOIP remains after primary and secondary oil recovery. This volume of remaining oil in-place (ROIP) is the "prize" for CO_2-EOR.

Table 8 provides information (as of year 2000) on oil production history and remaining oil in place for 10 large Illinois oil fields, each with estimated ultimate recovery of 50 million barrels or more. Of particular note are the large light oil fields that may be attractive for miscible CO_2-EOR, including: Clay City Consolidated with 602 million barrels of ROIP and Roland Consolidated with 143 million barrels of ROIP.

Table 8. Selected Major Oil Fields of Illinois

	Field	Year Discovered	Cumulative Production (Mbbl)	Estimated Reserves (Mbbl)	Remaining Oil In-Place (Mbbl)
1	Lawrence	1906	427,863	13,242	630,944
2	Louden	1937	393,704	4,373	549,358
3	Salem Consol.	1938	398,871	6,859	529,531
4	Clay City Consol.	1937	365,636	1,860	601,710
5	Main Consol.	1906	240,514	7,888	567,279
6	New Harmony Consol.	1939	132,767	3,989	176,489
7	Dale Consol.	1940	95,984	570	170,447
8	Sailor Springs Consol.	1938	68,253	2,299	147,501
9	Roland Consol.	1939	59,639	1,465	142,575
10	Centralia	1937	51,644	179	63,340

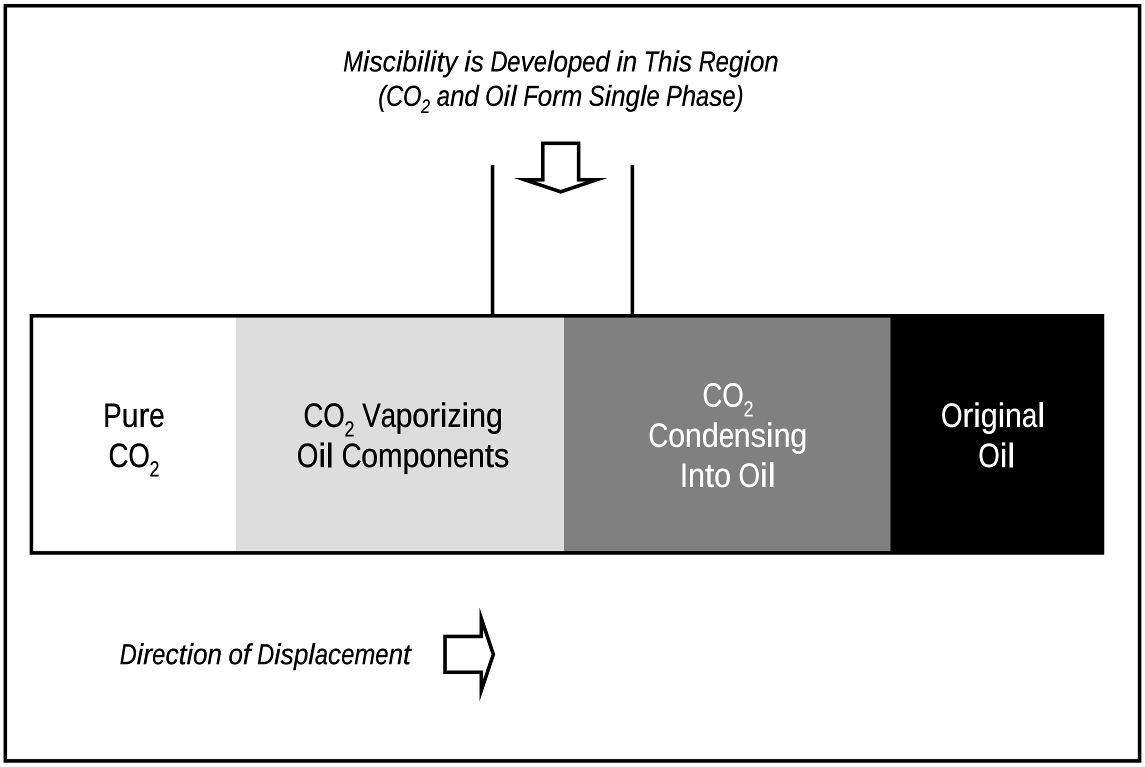
3.4 REVIEW OF PRIOR STUDIES. No recent studies of the potential for CO_2 enhanced oil recovery in Illinois oil reservoirs have been conducted since the National Petroleum Council's 1984 and 1976 studies. However these studies were conducted for the United States as a whole and did not report the results by state.

4. MECHANISMS OF CO_2-EOR

4.1 MECHANISMS OF MISCIBLE CO_2-EOR. Miscible CO_2-EOR is a multiple contact process, involving the injected CO_2 and the reservoir's oil. During this multiple contact process, CO_2 will vaporize the lighter oil fractions into the injected CO_2 phase and CO_2 will condense into the reservoir's oil phase. This leads to two reservoir fluids that become miscible (mixing in all parts), with favorable properties of low viscosity, a mobile fluid and low interfacial tension.

The primary objective of miscible CO_2-EOR is to remobilize and dramatically reduce the after waterflooding residual oil saturation in the reservoir's pore space. Figure 6 provides a one-dimensional schematic showing the various fluid phases existing in the reservoir and the dynamics of the CO_2 miscible process.

Figure 5. One-Dimensional Schematic Showing the CO_2 Miscible Process.



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4.2 MECHANISMS OF IMMISCIBLE CO_2-EOR. When insufficient reservoir pressure is available or the reservoir's oil composition is less favorable (heavier), the injected CO_2 is immiscible with the reservoir's oil. As such, another oil displacement mechanism, immiscible CO_2 flooding, occurs. The main mechanisms involved in immiscible CO_2 flooding are: (1) oil phase swelling, as the oil becomes saturated with CO_2; (2) viscosity reduction of the swollen oil and CO_2 mixture; (3) extraction of lighter hydrocarbon into the CO_2 phase; and, (4) fluid drive plus pressure. This combination of mechanisms enables a portion of the reservoir's remaining oil to be mobilized and produced. In general, immiscible CO_2-EOR is less efficient than miscible CO_2-EOR in recovering the oil remaining in the reservoir.

4.3 INTERACTIONS BETWEEN INJECTED CO_2 AND RESERVOIR OIL. The properties of CO_2 (as is the case for most gases) change with the application of pressure and temperature. Figures 7A and 7B provide basic information on the change in CO_2 density and viscosity, two important oil recovery mechanisms, as a function of pressure.

Oil swelling is an important oil recovery mechanism, for both miscible and immiscible CO_2-EOR. Figures 8A and 8B show the oil swelling (and implied residual oil mobilization) that occurs from: (1) CO_2 injection into a West Texas light reservoir oil; and, (2) CO_2 injection into a very heavy (12^{o}API) oil reservoir in Turkey. Laboratory work on the Bradford Field (Pennsylvania) oil reservoir showed that the injection of CO_2, at 800 psig, increased the volume of the reservoir's oil by 50%. Similar laboratory work on Mannville "D" Pool (Canada) reservoir oil showed that the injection of 872 scf of CO_2 per barrel of oil (at 1,450 psig) increased the oil volume by 28%, for crude oil already saturated with methane.

Viscosity reduction is a second important oil recovery mechanism, particularly for immiscible CO_2-EOR. Figure 9 shows the dramatic viscosity reduction of one to two orders of magnitude (10 to 100 fold) that occur for a reservoir's oil with the injection of CO_2 at high pressure.

Figure 6A. Carbon Dioxide, CH_4 and N_2 densities at 105°F. At high pressures, CO_2 has a density close to that of a liquid and much greater than t hat of either methane or nitrogen. Densities were calculated with an equation of state (EOS).

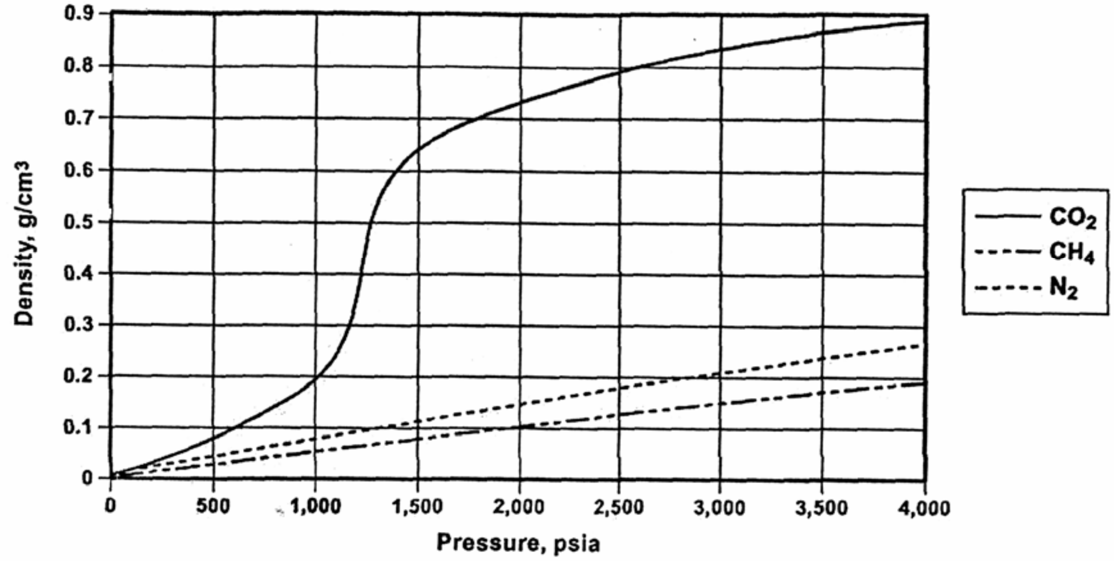

Figure 6B. Carbon Dioxide, CH_4 and N_2 viscosities at 105°F. At high pressures, the viscosity of CO_2 is also greater then that of methane or nitrogen, although it r emains low in comparison to that of liquids. Viscosities were calculat ed with an EOS.

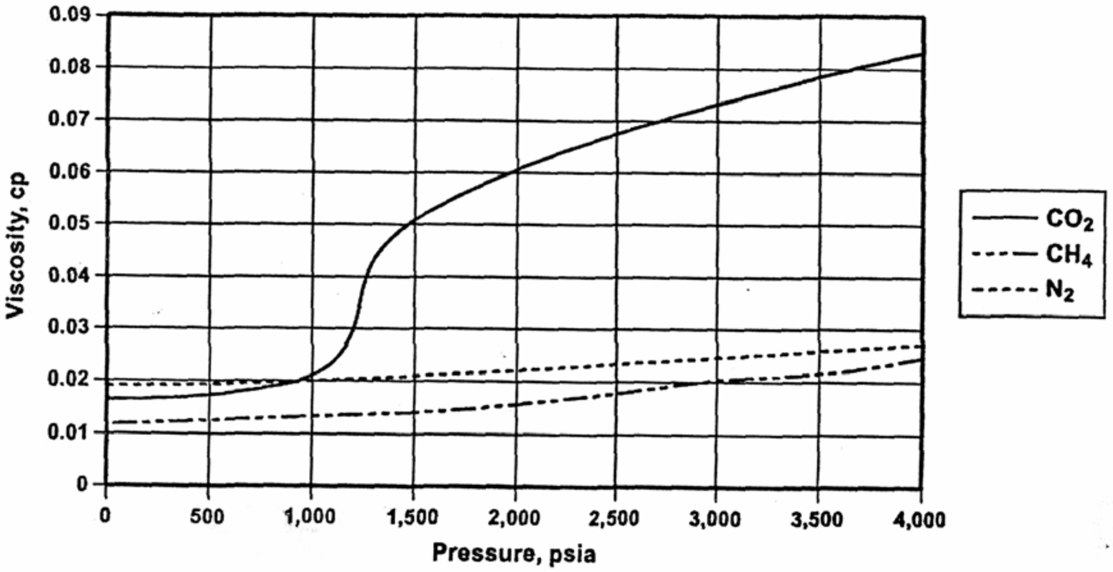

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Figure 7A. Relative Oil Volume vs. Pressure for a Light West Texas Reservoir Fluid. (Holm and Josendal)

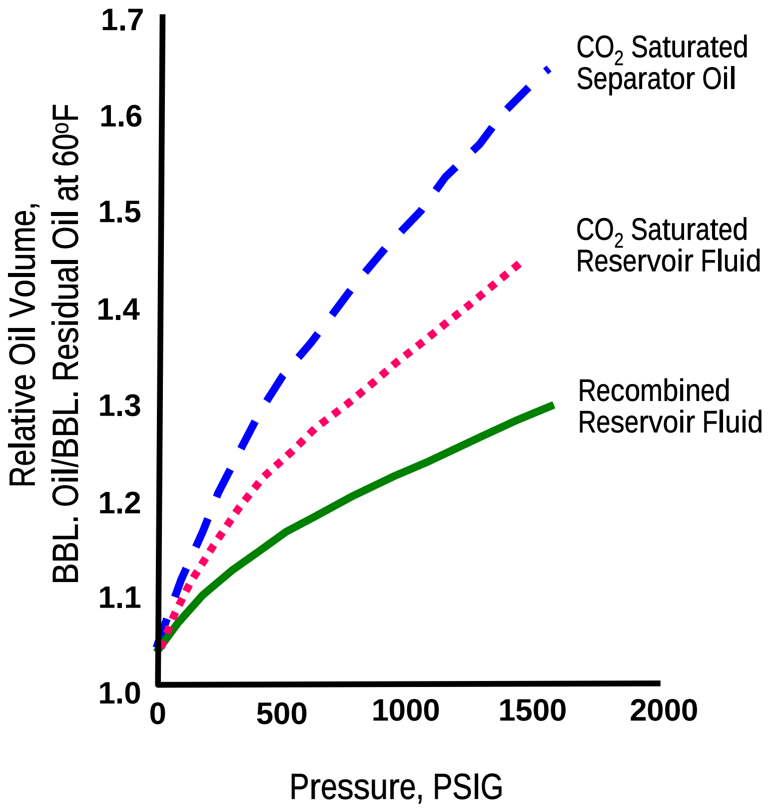

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Figure 7B. Oil Swelling Factor vs. Pressure for a Heavy Oil in Turkey (Issever and Topkoya).

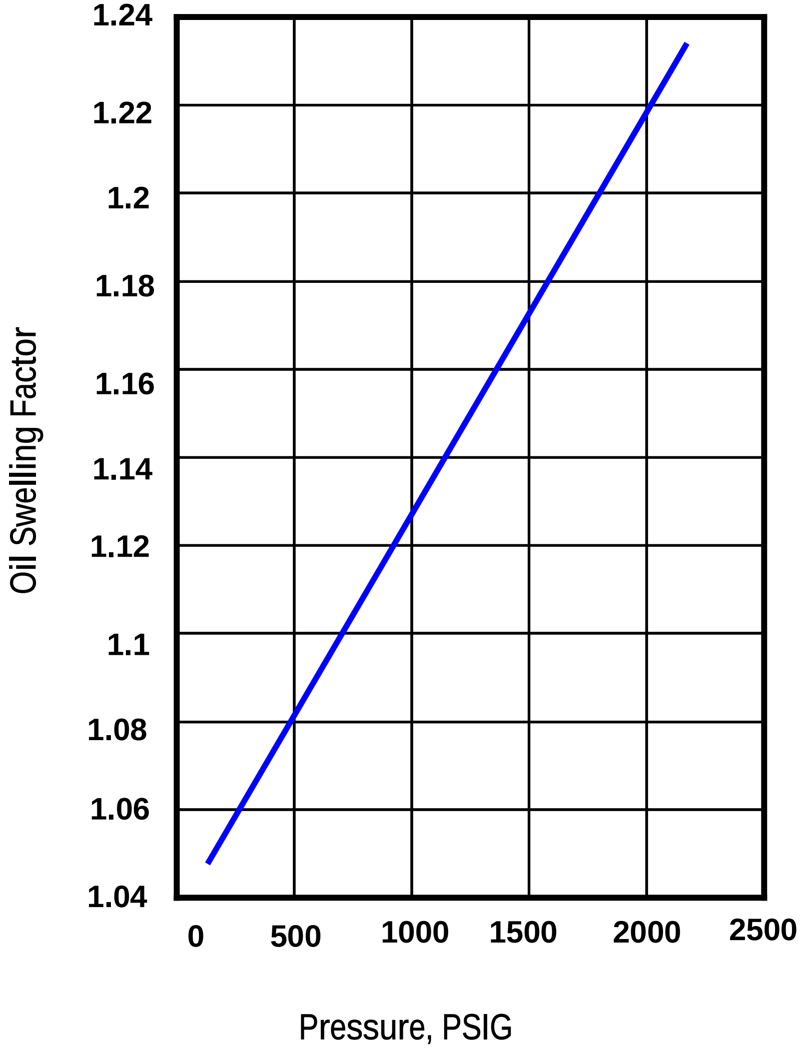
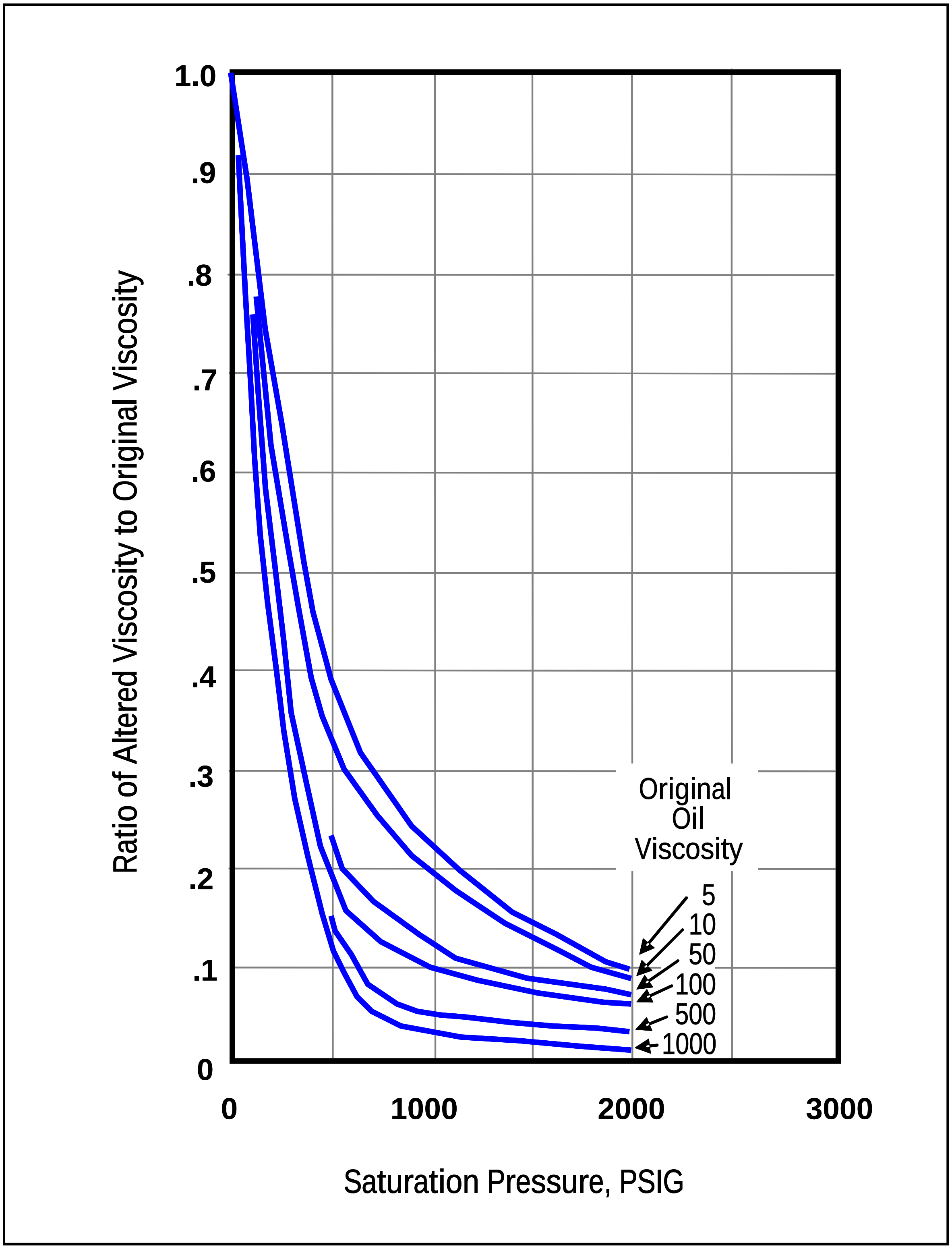


Figure 8. Viscosity Reduction Versus Saturation pressure (Simon and Graue)



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5. STUDY METHODOLOGY

5.1 OVERVIEW. A six part methodology was used to assess the CO_2-EOR potential of Illinois' oil reservoirs. The seven steps were: (1) assembling the Illinois Major Oil Reservoirs Data Base; (2) screening reservoirs for CO_2-EOR; (3) calculating the minimum miscibility pressure; (4) calculating oil recovery; (5) assembling the cost model; and, (6) conducting economic and sensitivity analyses.

An important objective of the study was the development of a desktop model with analytic capability for "basin oriented strategies" that would enable DOE/FE to develop policies and research programs leading to increased recovery and production of domestic oil resources. As such, this desktop model complements, but does not duplicate, the more extensive TORIS modeling system maintained by DOE/FE's National Energy Technology Laboratory.

5.2 ASSEMBLING THE MAJOR OIL RESERVOIRS DATA BASE. The study started with the National Petroleum Council (NPC) Public Data Base, maintained by DOE Fossil Energy. The study updated and modified this publicly accessible data base to develop the Illinois Major Oil Reservoirs Data Base.

Table 9 illustrates the oil reservoir data recording format developed by the study. The data format readily integrates with the input data required by the CO_2-EOR screening and oil recovery models, discussed below. Overall, the Illinois Major Oil Reservoirs Data Base contains 86 reservoirs, accounting for 68.7% of the oil expected to be ultimately produced in Illinois by primary and secondary oil recovery processes.

Table 9. Reservoir Data Format: Major Oil Reservoirs Data Base.

Basin Name	
Field Name	
Reservoir	

Reservoir Parameters:

Area (A)	
Net Pay (ft)	
Depth (ft)	
Porosity	
Reservoir Temp (deg F)	
Initial Pressure (psi)	
Pressure (psi)	
B_{oi}	
B_o @ S_o, swept	
S_{oi}	
S_{or}	
Swept Zone S_o	
S_{wi}	
S_w	
API Gravity	
Viscosity (cp)	
Dykstra-Parsons	

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Oil Production

Producing Wells (active)	
Producing Wells (shut-in)	
2001 Production (Mbbl)	
Daily Prod - Field (Bbl/d)	
Cum Oil Production (MMbbl)	
EOY 2001 Oil Reserves (MMbbl)	
Water Cut	

Water Production

2001 Water Production (Mbbl)	
Daily Water (Mbbl/d)	

Injection

Injection Wells (active)	
Injection Wells (shut-in)	
2001 Water Injection (MMbbl)	
Daily Injection - Field (Mbbl/d)	
Cum Injection (MMbbl)	
Daily Inj per Well (Bbl/d)	

Volumes

OOIP (MMbl)	
Cum Oil (MMbl)	
EOY 2001 Reserves (MMbl)	
Ultimate Recovery (MMbl)	
Remaining (MMbbl)	
Ultimate Recovered (%)	

OOIP Volume Check

Reservoir Volume (AF)	
Bbl/AF	
OOIP Check (MMbl)	

SROIP Volume Check

Reservoir Volume (AF)	
Swept Zone Bbl/AF	
SROIP Check (MMbbl)	

ROIP Volume Check

ROIP Check (MMbl)	

Considerable effort was required to construct an up-to-date, volumetrically consistent data base that contained all of the essential data, formats and interfaces to enable the study to: (1) develop an accurate estimate of the size of the original and remaining oil in-place in Illinois; (2) reliably screen the reservoirs as to their amenability for miscible and immiscible CO_2-EOR; and, (3) provide the *CO_2-PROPHET* Model (developed by Texaco for the DOE Class I cost-share program) the essential input data for calculating CO_2 injection requirements and oil recovery.

5.3 SCREENING RESERVOIRS FOR CO_2-EOR. The data base was screened for reservoirs that would be applicable for CO_2-EOR. Five prominent screening criteria were used to identify favorable reservoirs. These were: reservoir depth, oil gravity, reservoir pressure, reservoir temperature and oil composition. These values were used to establish the minimum miscibility pressure for conducting miscible CO_2-EOR and for selecting reservoirs that would be amenable to this oil recovery process. Reservoirs not meeting the miscibility pressure standard were considered for immiscible CO_2-EOR.

The preliminary screening steps involved selecting the oil reservoirs that had sufficiently high oil gravity. A minimum reservoir depth of 2,000 feet, at the mid-point of the reservoir, was used to ensure the reservoir could accommodate high pressure CO_2 injection. A minimum oil gravity of 25^o API was used to ensure the reservoir's oil had sufficient mobility. Table 10 tabulates the oil reservoirs that passed the preliminary screening step. Many of these fields contain multiple reservoirs, with each reservoir holding a great number of stacked sands. Because of data limitations, this screening study combined the sands into a single reservoir.

Table 10. Illinois Oil Reservoirs Screened Acceptable for Miscible and Immiscible CO_2-EOR

Basin	Field	Formation
A. Illinois		
Illinois	ALBION	AUX VASES
Illinois	ALBION	MCCLOSKEY
Illinois	CLAY CITY CONSOLIDATED	OHARA
Illinois	CLAY CITY CONSOLIDATED	SPAR MOUNTAIN
Illinois	CLAY CITY CONSOLIDATED	MCCLOSKEY
Illinois	CLAY CITY CONSOLIDATED	ST LOUIS
Illinois	CLAY CITY CONSOLIDATED	SALEM
Illinois	DALE CITY	AUX VASES
Illinois	JOHNSONVILLE CONSOLIDATED	AUX VASES
Illinois	JOHNSONVILLE CONSOLIDATED	MCCLOSKEY
Illinois	JOHNSONVILLE CONSOLIDATED	SALEM
Illinois	PHILLIPSTOWN CONSOLIDATED	MCCLOSKEY
Illinois	ROLAND CONSOLIDATED	MCCLOSKEY
Illinois	ST JAMES	CARPER
Illinois	SALEM CONSOLIDATED	DEVONIAN
Illinois	SALEM CONSOLIDATED	TRENTON
Illinois	ALBION	BETHEL
Illinois	ALBION	BIEHL
Illinois	ALBION	CYPRESS
Illinois	BENTON	TAR SPRINGS
Illinois	CENTRALIA	DEVONIAN
Illinois	CLAY CITY CONSOLIDATED	AUX VASES
Illinois	CLAY CITY CONSOLIDATED	CYPRESS
Illinois	DALE CITY	BETHEL
Illinois	INMAN EAST AND WEST	AUX VASES
Illinois	INMAN EAST AND WEST	CYPRESS
Illinois	INMAN EAST AND WEST	TAR SPRINGS
Illinois	NEW HARMONY CONSLIDATED	AUX VASES
Illinois	NEW HARMONY CONSLIDATED	BETHEL
Illinois	NEW HARMONY CONSLIDATED	CYPRESS
Illinois	NEW HARMONY CONSLIDATED	MCCLOSKEY
Illinois	PHILLIPSTOWN CONSOLIDATED	AUX VASES
Illinois	PHILLIPSTOWN CONSOLIDATED	BETHEL
Illinois	PHILLIPSTOWN CONSOLIDATED	TAR SPRINGS
Illinois	PHILLIPSTOWN CONSOLIDATED	AUX VASES
Illinois	ROLAND CONSOLIDATED	BETHEL
Illinois	ROLAND CONSOLIDATED	CYPRESS
Illinois	ROLAND CONSOLIDATED	HARDINSBURG
Illinois	ROLAND CONSOLIDATED	WALTERSBURG

Table 10. Illinois Oil Reservoirs Screened Acceptable for Miscible and Immiscible CO_2-EOR

Basin	Field	Formation
Illinois	SAILOR SPRINGS	AUX VASES
Illinois	SAILOR SPRINGS	CYPRESS
Illinois	SAILOR SPRINGS	MCCLOSKEY
Illinois	SAILOR SPRINGS	SPAR MOUNTAIN
Illinois	SALEM CONSOLIDATED	MCCLOSKEY
Illinois	SALEM CONSOLIDATED	SALEM
Illinois	SALEM CONSOLIDATED	SPAR MOUNTAIN

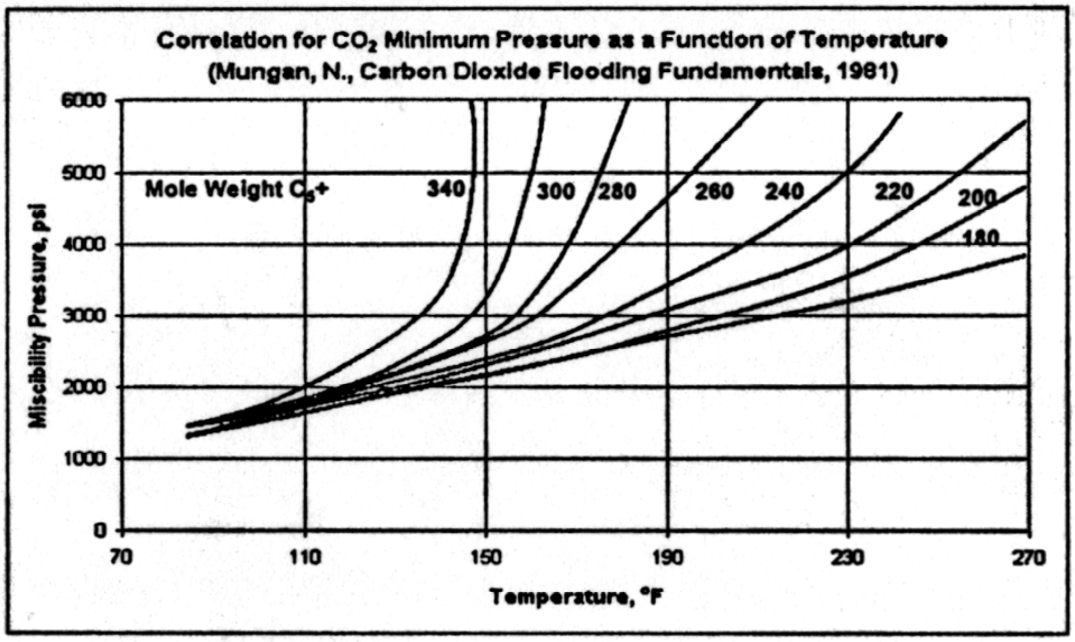
5.4 CALCULATING MINIMUM MISCIBILITY PRESSURE. The miscibility of a reservoir's oil with injected CO_2 is a function of pressure, temperature and the composition of the reservoir's oil. The study's approach to estimating whether a reservoir's oil will be miscible with CO_2, given fixed temperature and oil composition, was to determine whether the reservoir would hold sufficient pressure to attain miscibility. Where oil composition data was missing, a correlation was used for translating the reservoir's oil gravity to oil composition.

To determine the minimum miscibility pressure (MMP) for any given reservoir, the study used the Cronquist correlation, Figure 10. This formulation determines MMP based on reservoir temperature and the molecular weight (MW) of the pentanes and heavier fractions of the reservoir oil, without considering the mole percent of methane. (Most Illinois oil reservoirs have produced the bulk of their methane during primary and secondary recovery.) The Cronquist correlation is set forth below:

$$MMP = 15.988*T^{(0.744206+0.0011038*MW\ C5+)}$$

Where: T is Temperature in ^{o}F, and MW C5+ is the molecular weight of pentanes and heavier fractions in the reservoir's oil.

Figure 9. Estimating CO_2 Minimum Miscibility Pressure



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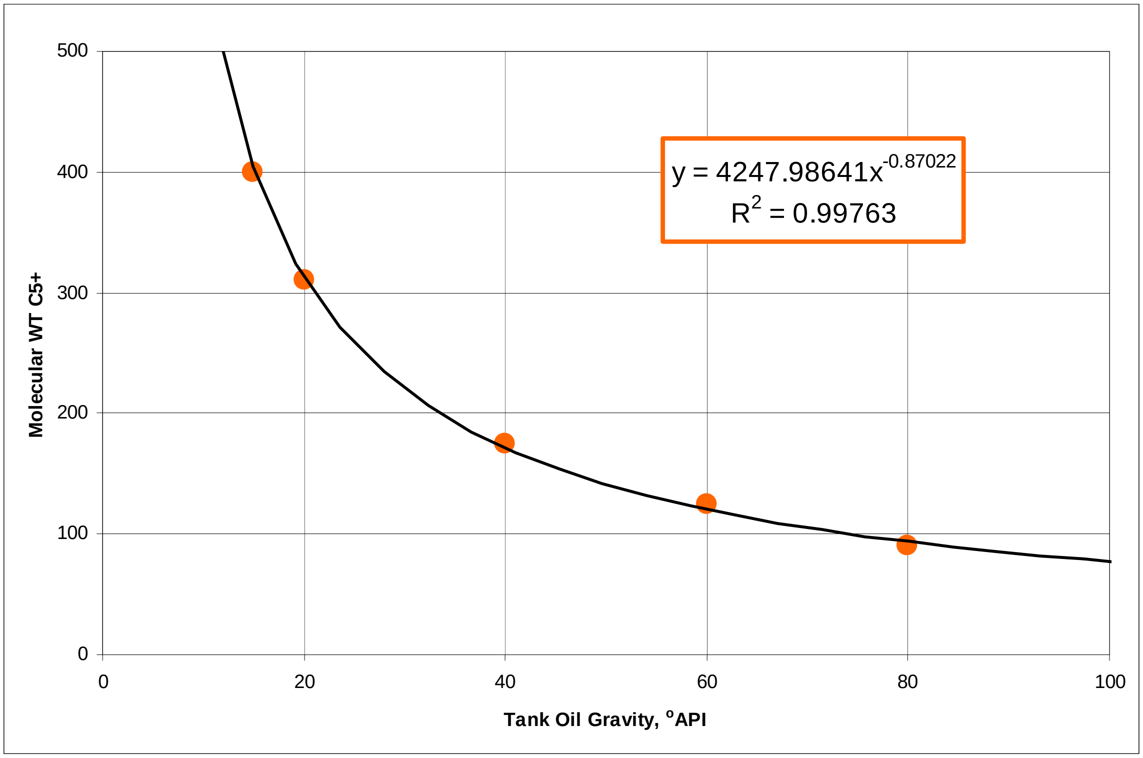
The temperature of the reservoir was taken from the data base or estimated from the thermal gradient in the basin. The molecular weight of the pentanes and heavier fraction of the oil was obtained from the data base or was estimated from a correlative plot of MW C5+ and oil gravity, shown in Figure 11.

The next step was calculating the minimum miscibility pressure (MMP) for a given reservoir and comparing it to the maximum allowable pressure. The maximum pressure was determined using a pressure gradient of 0.6 psi/foot. If the minimum miscibility pressure was below the maximum injection pressure, the reservoir was classified as a miscible flood candidate. Oil reservoirs that did not screen positively for miscible CO_2-EOR were selected for consideration by immiscible CO_2-EOR.

Figure 10. Correlation of MW C5+ to Tank Oil Gravity



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5.5 CALCULATING OIL RECOVERY. The study utilized *CO_2-PROPHET* to calculate incremental oil produced using CO_2-EOR. *CO_2-PROPHET* was developed by the Texaco Exploration and Production Technology Department (EPTD) as part of the DOE Class I cost-share program. The specific project was "Post Waterflood CO_2 Flood in a Light Oil, Fluvial Dominated Deltaic Reservoir" (DOE Contract No. DE-FC22-93BC14960). *CO_2-PROPHET* was developed as an alternative to the DOE's CO_2 miscible flood predictive model, *CO_2PM*. According to the developers of the model, *CO_2-PROPHET* has more capabilities and fewer limitations than *CO_2PM*. For example, according to the above cited report, *CO_2-PROPHET* performs two main operations that provide a more robust calculation of oil recovery than available from *CO_2PM*:

- *CO_2-PROPHET* generates streamlines for fluid flow between injection and production wells, and

- The model performs oil displacement and recovery calculations along the established streamlines. (A finite difference routine is used for oil displacement calculations.)

Appendix A discusses, in more detail, the *CO_2-PROPHET* model and the calibration of this model with an industry standard reservoir simulator.

Even with these improvements, it is important to note the CO_2-PROPHET is still primarily a "screening-type" model, and lacks some of the key features, such as gravity override and compositional changes to fluid phases, available in more sophisticated reservoir simulators.

5.6 ASSEMBLING THE COST MODEL. A detailed, up-to-date CO_2-EOR Cost Model was developed by the study. The model includes costs for: (1) drilling new wells or reworking existing wells; (2) providing surface equipment for new wells; (3) installing the CO_2 recycle plant; (4) constructing a CO_2 spur-line from the main CO_2 trunkline to the oil field; and, (5) various miscellaneous costs.

The cost model also accounts for normal well operation and maintenance (O&M), for lifting costs of the produced fluids, and for costs of capturing, separating and reinjecting the produced CO_2. A variety of CO_2 purchase and reinjection costs options are available to the model user. (Appendices B, C and D provide state-level details on the Cost Model for CO_2-EOR prepared by this study.)

5.7 CONSTRUCTING AN ECONOMICS MODEL. The economic model used by the study is an industry standard cash flow model that can be run on either a pattern or a field-wide basis. The economic model accounts for royalties, severance and ad valorem taxes, as well as any oil gravity and market location discounts (or premiums) from the "marker" oil price. A variety of oil prices are available to the model user. Table 12 provides an example of the Economic Model for CO_2-EOR used by the study.

5.8 PERFORMING SCENARIO ANALYSES. A series of analyses were prepared to better understand how differences in oil prices, CO_2 supply costs and financial risk hurdles could impact the volumes of oil that would be economically produced by CO_2-EOR from Illinois' major oil reservoirs.

- Two technology cases were examined. As discussed in more detail in Chapter 2, the study examined the application of two CO_2-EOR options - - "Traditional Practices" and "State of the Art" Technology.

- Two oil prices were considered. A \$25 per barrel oil price was used to represent the moderate oil price case; a \$35 per barrel oil price was used to represent the availability of Federal/state "risk mitigating" and/or the continuation of the current high oil price situation.

- Two CO_2 supply costs were considered. The high CO_2 cost was set at \$1.25 per Mcf to represent the costs of a new transportation system bringing natural CO_2 to Illinois' oil basins. A lower CO_2 supply cost equal to \$0.70 per Mcf was included to represent the potential future availability of low-cost CO_2 from industrial and power plants as part of CO_2 storage.

- Two minimum rate of return (ROR) hurdles were considered, a high ROR of 25%, before tax, and a lower 15% ROR, before tax. The high ROR hurdle incorporates a premium for the market, reservoir and technology risks inherent in using CO_2-EOR in a new reservoir setting. The lower ROR hurdle represents application of CO_2-EOR after the geologic and technical risks have been mitigated with a robust program of field pilots and demonstrations.

These various technology, oil price, CO_2 supply cost and rate of return hurdles were combined into four scenarios, as set forth below:

- The first scenario captures how CO_2-EOR technology has been applied and has performed in the past. This low technology, high risk scenario is called “Traditional Practices”.
- The second scenario, entitled “State of the Art”, assumes that the technology progress in CO_2-EOR, achieved in other areas, is successfully applied to the oil reservoirs of Illinois. In addition, a comprehensive set of research, pilot tests and field demonstrations help lower the risk inherent in applying new technology to these complex oil reservoirs. However, because of limited sources of CO_2, these supply costs are high (equal to $1.25 per Mcf) the oil price) and significantly hamper economic feasibility of using CO_2-EOR.
- The third scenario, entitled “Risk Mitigation,” examines how the economic potential of CO_2-EOR could be increased through a strategy involving increased federal investment tax credits and royalty relief that together would add an equivalent of $10 per barrel to the WTI marker price for crude oil. (Illinois does not have a severance tax on produced crude oil.)
- In the final scenario, entitled “Ample Supplies of CO_2,” low-cost, “EOR-ready” CO_2 supplies (equal to $0.70 per Mcf) are aggregated from various sources. These include industrial high-concentration CO_2 emissions from hydrogen facilities, gas processing plants and other industrial sources. These would be augmented, in the longer-term, from low CO_2 concentration sources including combustion and electric generation plants. Capture of industrial CO_2 emissions would be part of national efforts for reducing greenhouse gas emissions.

Table 11. Economic Model Established by the Study

Pattern-Level Cashflow Model		**Advanced Technology**											
State													
Field				New Injectors	0.51			21					
Formation				Existing Injectors	0.00								
Depth				Convertable Producers	0.49								
Distance from Trunkline (mi)				New Producers	0.0								
# of Patterns				Existing Producers	1.09								
Miscibility:	**Miscible**												
	Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
CO2 Injection (MMcf)			731	731	731	731	731	731	731	682	656	656	656
H2O Injection (Mbw)			183	183	183	183	183	183	183	207	220	220	220
Oil Production (Mbbl)			-	11	136	88	62	76	62	53	38	39	38
H2O Production (MBw)			579	568	339	275	275	249	236	222	246	250	253
CO2 Production (MMcf)			-	0	187	394	444	466	515	556	537	528	524
CO2 Purchased (MMcf)			731	730	543	337	286	265	215	127	119	128	132
CO2 Recycled (MMcf)			-	0	187	394	444	466	515	556	537	528	524
Oil Price ($/Bbl)	**$ 25.00**		$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00
Gravity Adjustment	**35**	Deg	$ 27.25	$ 27.25	$ 27.25	$ 27.25	$ 27.25	$ 27.25	$ 27.25	$ 27.25	$ 27.25	$ 27.25	$ 27.25
Gross Revenues ($M)			$ -	$ 305	$ 3,714	$ 2,409	$ 1,695	$ 2,066	$ 1,692	$ 1,433	$ 1,033	$ 1,049	$ 1,041
Royalty ($M)	**-12.5%**		$ -	$ (38)	$ (464)	$ (301)	$ (212)	$ (258)	$ (212)	$ (179)	$ (129)	$ (131)	$ (130)
Severance Taxes ($M)	**-5.0%**		$ -	$ (13)	$ (162)	$ (105)	$ (74)	$ (90)	$ (74)	$ (63)	$ (45)	$ (46)	$ (46)
Ad Valorum ($M)	**-2.5%**		$ -	$ (7)	$ (81)	$ (53)	$ (37)	$ (45)	$ (37)	$ (31)	$ (23)	$ (23)	$ (23)
Net Revenue($M)			$ -	$ 247	$ 3,006	$ 1,950	$ 1,372	$ 1,672	$ 1,370	$ 1,160	$ 836	$ 849	$ 843
Capital Costs ($M)													
New Well - D&C		$ (274)											
Reworks - Producers to Producers		$ (54)											
Reworks - Producers to Injectors		$ (23)											
Reworks - Injectors to Injectors		$ -											
Surface Equipment (new wells only)		$ (81)											
Recycling Plant		$ -	$ (1,147)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Trunkline Construction		$ (4)											
Total Capital Costs		$ (436)	$ (1,147)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
CO2 Costs ($M)													
Total CO2 Cost ($M)			$ (913.1)	$ (913)	$ (726)	$ (519)	$ (469)	$ (447)	$ (398)	$ (298)	$ (283)	$ (292)	$ (296)
O&M Costs													
Operating & Maintenance ($M)			$ (103)	$ (103)	$ (103)	$ (103)	$ (103)	$ (103)	$ (103)	$ (103)	$ (103)	$ (103)	$ (103)
Lifting Costs ($/bbl)	**$ 0.25**		$ (145)	$ (145)	$ (119)	$ (91)	$ (84)	$ (81)	$ (75)	$ (69)	$ (71)	$ (72)	$ (73)
G&A	**20%**		(50)	(50)	(44)	(39)	(38)	(37)	(36)	(34)	(35)	(35)	(35)
Total O&M Costs			$ (298)	$ (298)	$ (267)	$ (233)	$ (225)	$ (221)	$ (213)	$ (206)	$ (209)	$ (211)	$ (211)
Net Cash Flow ($M)		$ (436)	$ (2,357)	$ (964)	$ 2,014	$ 1,197	$ 678	$ 1,003	$ 758	$ 656	$ 343	$ 347	$ 335
Cum. Cash Flow		$ (436)	$ (2,794)	$ (3,757)	$ (1,744)	$ (546)	$ 132	$ 1,135	$ 1,893	$ 2,549	$ 2,893	$ 3,240	$ 3,575
Discount Factor	**15%**	1.00	0.87	0.76	0.66	0.57	0.50	0.43	0.38	0.33	0.28	0.25	0.21
Disc. Net Cash Flow		$ (436)	$ (2,050)	$ (729)	$ 1,324	$ 685	$ 337	$ 434	$ 285	$ 215	$ 98	$ 86	$ 72
Disc. Cum Cash Flow		$ (436)	$ (2,486)	$ (3,215)	$ (1,891)	$ (1,206)	$ (869)	$ (435)	$ (150)	$ 64	$ 162	$ 248	$ 320
NPV (BTx)	25%	($401)											
NPV (BTx)	20%	$79											
NPV (BTx)	15%	$805											
NPV (BTx)	10%	$1,954											JAF2004054.XLS
IRR (BTx)		20.69%											

Table 11. Economic Model Established by the Study (Cont'd)

	Pattern-Level Cashflow Model														
	State														
	Field														
	Formation														
	Depth														
	Distance from Trunkline (mi)														
	# of Patterns														
	Miscibility:	**Miscible**													
		Year	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
1	CO2 Injection (MMcf)		656	656	656	656	656	656	656	656	416	-	-	-	-	-
2	H2O Injection (Mbw)		220	220	220	220	220	220	220	220	340	548	548	161	-	-
3	Oil Production (Mbbl)		41	58	57	52	38	26	23	21	19	19	17	4	-	-
4	H2O Production (MBw)		245	229	224	216	223	224	222	222	226	289	411	131	-	-
5	CO2 Production (MMcf)		533	530	543	565	579	600	608	613	590	442	221	47	-	-
6	CO2 Purchased (MMcf)		123	126	113	91	78	56	48	43	-	-	-	-	-	-
7	CO2 Recycled (MMcf)		533	530	543	565	579	600	608	613	416	-	-	-	-	-
8	Oil Price ($/Bbl)	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ -	$ -
	Gravity Adjustment	35	$ 27.25	$ 27.25	$ 27.25	$ 27.25	$ 27.25	$ 27.25	$ 27.25	$ 27.25	$ 27.25	$ 27.25	$ 27.25	$ 27.25	$ -	$ -
9	Gross Revenues ($M)		$ 1,109	$ 1,583	$ 1,551	$ 1,420	$ 1,038	$ 695	$ 638	$ 575	$ 523	$ 526	$ 463	$ 120	$ -	$ -
10	Royalty ($M)	-12.5%	$ (139)	$ (198)	$ (194)	$ (177)	$ (130)	$ (87)	$ (80)	$ (72)	$ (65)	$ (66)	$ (58)	$ (15)	$ -	$ -
12	Severance Taxes ($M)	-5.0%	$ (49)	$ (69)	$ (68)	$ (62)	$ (45)	$ (30)	$ (28)	$ (25)	$ (23)	$ (23)	$ (20)	$ (5)	$ -	$ -
13	Ad Valorum ($M)	-2.5%	$ (24)	$ (35)	$ (34)	$ (31)	$ (23)	$ (15)	$ (14)	$ (13)	$ (11)	$ (12)	$ (10)	$ (3)	$ -	$ -
11	Net Revenue($M)		$ 898	$ 1,281	$ 1,255	$ 1,149	$ 840	$ 562	$ 516	$ 465	$ 423	$ 426	$ 375	$ 97	$ -	$ -
	Capital Costs ($M)															
	New Well - D&C															
	Reworks - Producers to Producers															
	Reworks - Producers to Injectors															
	Reworks - Injectors to Injectors															
	Surface Equipment (new wells only)															
	Recycling Plant		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Trunkline Construction															
	Total Capital Costs		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	CO2 Costs ($M)															
	Total CO2 Cost ($M)		$ (287)	$ (291)	$ (277)	$ (255)	$ (242)	$ (220)	$ (212)	$ (207)	$ (104)	$ -	$ -	$ -	$ -	$ -
	O&M Costs															
	Operating & Maintenance ($M)		$ (103)	$ (103)	$ (103)	$ (103)	$ (103)	$ (103)	$ (103)	$ (103)	$ (103)	$ (103)	$ (103)	$ (103)	$ -	$ -
	Lifting Costs ($/bbl)	$ 0.25	$ (71)	$ (72)	$ (70)	$ (67)	$ (65)	$ (62)	$ (61)	$ (61)	$ (61)	$ (77)	$ (107)	$ (34)	$ -	$ -
	G&A	20%	(35)	(35)	(35)	(34)	(34)	(33)	(33)	(33)	(33)	(36)	(42)	(27)	-	-
	Total O&M Costs		$ (210)	$ (210)	$ (208)	$ (205)	$ (202)	$ (199)	$ (198)	$ (197)	$ (198)	$ (216)	$ (252)	$ (165)	$ -	$ -
	Net Cash Flow ($M)		$ 401	$ 781	$ 769	$ 689	$ 396	$ 143	$ 106	$ 61	$ 122	$ 209	$ 123	$ (68)	$ -	$ -
	Cum. Cash Flow		$ 3,976	$ 4,757	$ 5,526	$ 6,216	$ 6,612	$ 6,755	$ 6,862	$ 6,923	$ 7,045	$ 7,254	$ 7,377	$ 7,309	$ 7,309	$ 7,309
	Discount Factor	15%	0.19	0.16	0.14	0.12	0.11	0.09	0.08	0.07	0.06	0.05	0.05	0.04	0.03	0.03
	Disc. Net Cash Flow		$ 75	$ 127	$ 109	$ 85	$ 42	$ 13	$ 9	$ 4	$ 7	$ 11	$ 6	$ (3)	$ -	$ -
	Disc. Cum Cash Flow		$ 395	$ 521	$ 630	$ 715	$ 757	$ 771	$ 779	$ 783	$ 791	$ 802	$ 808	$ 805	$ 805	$ 805

Table 11. Economic Model Established by the Study (Cont'd)

	Pattern-Level Cashflow Model													
	State													
	Field													
	Formation													
	Depth													
	Distance from Trunkline (mi)													
	# of Patterns													
	Miscibility:	**Miscible**												
		Year	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	
1	CO2 Injection (MMcf)		-	-	-	-	-	-	-	-	-	-	-	13,429
2	H2O Injection (Mbw)		-	-	-	-	-	-	-	-	-	-	-	5,500
3	Oil Production (Mbbl)		-	-	-	-	-	-	-	-	-	-	-	979
4	H2O Production (MBw)		-	-	-	-	-	-	-	-	-	-	-	6,354
5	CO2 Production (MMcf)		-	-	-	-	-	-	-	-	-	-	-	10,022
6	CO2 Purchased (MMcf)		-	-	-	-	-	-	-	-	-	-	-	4,291
7	CO2 Recycled (MMcf)		-	-	-	-	-	-	-	-	-	-	-	9,138
8	Oil Price ($/Bbl)	**$ 25.00**	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
	Gravity Adjustment	**35**	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
9	Gross Revenues ($M)		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 26,678
10	Royalty ($M)	**-12.5%**	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (3,335)
12	Severance Taxes ($M)	**-5.0%**	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (1,167)
13	Ad Valorum ($M)	**-2.5%**	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (584)
11	Net Revenue($M)		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 21,592
	Capital Costs ($M)													
	New Well - D&C													$ (274)
	Reworks - Producers to Producers													$ (54)
	Reworks - Producers to Injectors													$ (23)
	Reworks - Injectors to Injectors													$ -
	Surface Equipment (new wells only)													$ (81)
	Recycling Plant		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (1,147)
	Trunkline Construction													$ (4)
	Total Capital Costs		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (1,583)
	CO2 Costs ($M)													
	Total CO2 Cost ($M)		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (7,649)
	O&M Costs													
	Operating & Maintenance ($M)		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (2,377)
	Lifting Costs ($/bbl)	**$ 0.25**	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (1,833)
	G&A	**20%**	-	-	-	-	-	-	-	-	-	-	-	$ (842)
	Total O&M Costs		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (5,052)
	Net Cash Flow ($M)		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 7,309
	Cum. Cash Flow		$ 7,309	$ 7,309	$ 7,309	$ 7,309	$ 7,309	$7,309	$7,309	$7,309	$7,309	$7,309	$7,309	
	Discount Factor	**15%**	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	
	Disc. Net Cash Flow		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 805
	Disc. Cum Cash Flow		$ 805	$ 805	$ 805	$ 805	$ 805	$ 805	$ 805	$ 805	$ 805	$ 805	$ 805	

6. STUDY RESULTS

6.1 ILLINOIS OIL PRODUCTION. Illinois is a major oil producing state with a rich history of oil recovery. Crude oil production began in 1889, and has reached a cumulative recovery of almost 3.6 billion barrels of oil to date. In 2002, the state ranked 14th in production in the U.S., producing 9 MMBbls of oil (24.6 MBbls/day) from 16,737 producing wells, and 14th in reserves at 107 MMBbls. Currently, only one of Illinois' four oil refineries has a hydrogen plant, located at ConocoPhillip's Wood River Refinery in western Illinois (hydrogen capacity of 57 MMcfd).

Illinois has seen its oil production remain relatively steady for the past several years, Table 12, although production had been declining sharply since the mid-1960s.

Table 12. Recent History of Illinois Oil Production

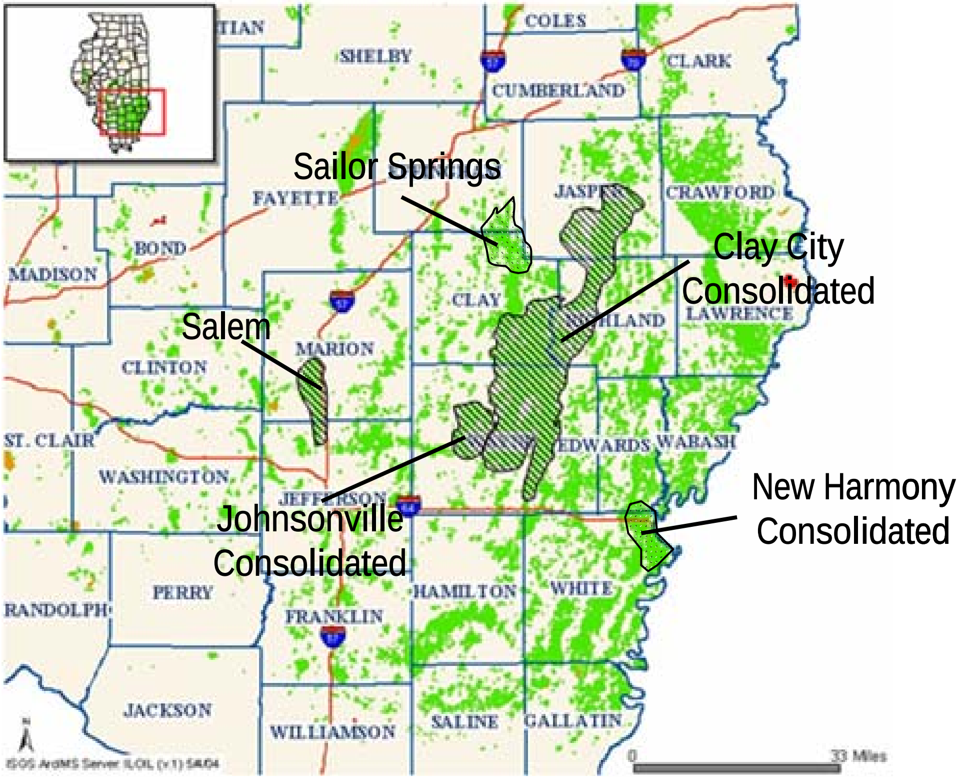
	Annual Oil Production	
	(MMBls/Yr)	(MBbls/D)
1999	9	25
2000	10	37
2001	10	37
2002	9	25

An active program of secondary oil recovery has helped maintain the recent level of oil production in the state. More than 160 oil fields representing 100 reservoirs in the state of Illinois have undergone waterflooding. However, these waterfloods are mature, with many of the fields near their production limits, calling for alternative methods for maintaining oil production.

6.2 MAJOR ILLINOIS OIL FIELDS. To better understand the potential of using CO_2-EOR in Illinois's light oil fields, this section examines, in more depth, five large field/reservoir combinations, shown in Figure 11. The stack of individual reservoirs in many of these fields has been grouped into:

- Clay City Consolidated (McCloskey)
- Salem Consolidated (Devonian)
- Johnsonville Consolidated (McCloskey)
- New Harmony Consolidated (Bethel)
- Sailor Springs (Cypress)

Figure 11. Illinois Anchor Fields



These five fields, distributed across the Illinois Basin, could serve as the “anchor” sites for the initial CO_2-EOR projects in the state that could later be extended to other fields. The cumulative oil production, proved reserves and remaining oil in place (ROIP) for these five “anchor” light oil fields are set forth in Table 13.

Table 13. Status of Illinois "Anchor" Fields/Reservoirs, 2000

	Anchor Fields/Reservoirs	Cumulative Production (MMBbls)	Proved Reserves (MMBbls)	Remaining Oil In Place (MMBbls)
1	Clay City Consolidated (McCloskey)	116	4	284
2	Salem Consolidated (Devonian)	75	1	98
3	Johnsonville Consolidated (McCloskey)	36	1	52
4	New Harmony Consolidated (Bethel)	41	1	63
5	Sailor Springs (Cypress)	31	1	60

These five large "anchor" fields, each with 50 or more million barrels of ROIP, may be favorable for miscible CO_2-EOR, based on their reservoir properties, Table 14.

Table 14. Reservoir Properties and Improved Oil Recovery Activity, "Anchor" Oil Fields/Reservoirs

	Anchor Fields	Depth (ft)	Oil Gravity (^oAPI)	Active Waterflood or Gas Injection
1	Clay City Consolidated (McCloskey)	3,050	39.0	Undergoing waterflooding
2	Salem Consolidated (Devonian)	3,440	40.0	Undergoing waterflooding
3	Johnsonville Consolidated (McCloskey)	3,170	38.0	Undergoing waterflooding
4	New Harmony Consolidated (Bethel)	2,700	37.0	Undergoing waterflooding
5	Sailor Springs (Cypress)	2,550	37.2	Undergoing waterflooding

6.3 PAST CO_2-EOR PROJECTS. Illinois oil fields have had only brief experiences with CO_2 injection. A small pilot was initiated in the Forsyth field, utilizing CO_2 from the Archer-Daniels-Midland Ethanol Processing Facility in Decatur, IL. Few results from this project have been published. In the early 1990s, a single-well huff-and-puff CO_2 pilot project began in the Mattoon field. Drilled to a depth of 1,800' in the Cypress Reservoir, this project also utilized CO_2 trucked from ADM's ethanol plant in Decatur, IL. After several months of operation, the pilot was shutdown due to high CO_2 costs compared to oil recovery. Currently, there is considerable work underway at locating and characterizing reservoirs suitable for CO_2-EOR.

6.4 FUTURE CO_2-EOR POTENTIAL. Illinois contains 16 reservoirs that are candidates for miscible CO_2-EOR and 30 reservoirs that are candidates for immiscible CO_2-EOR.

Under "Traditional Practices" (and Base Case financial conditions, defined above), there are no economically attractive oil reservoirs for miscible CO_2 flooding in Illinois. Applying "State of the Art Technology" (involving higher volume CO_2 injection) and lower risk financial conditions, the number of economically favorable oil reservoirs in Illinois increases to 21, providing 370 million barrels of additional oil recovery, Table 15.

Table 15. Economic Oil Recovery Potential Under Current Conditions, Illinois.

CO_2-EOR Technology	No. of Reservoirs Studied	Original Oil In-Place	Technical Potential	Economic Potential	
		(MMBbls)	(MMBbls)	(No. of Reservoirs)	(MMBbls)
"Traditional Practices"*	16	1,360	130	0	0
"State of Art Technology"**	46	3,120	490	21	370

*Assumes an oil price of $25 per barrel, a CO2 cost of $1.25 per Mcf and a ROR hurdle rate of 25% (before tax).
**Assumes an oil price of $25 per barrel, a CO2 cost of $1.25 per Mcf and a ROR hurdle rate of 15% (before tax).

Lower cost CO_2 supplies and risk mitigating/higher oil prices would enable CO_2-EOR in Illinois to recover up to 470 million barrels of oil (from 39 major reservoirs), Table 16.

Table 16. Economic Oil Recovery Potential with More Favorable Financial Conditions, Illinois

More Favorable Financial Conditions	No. of Economic Reservoirs	Economic Potential (MMBbls)
Plus: "Risk Mitigation"*	39	470
Plus: Low Cost CO_2**	39	470

** Assumes an equivalent of $10 per barrel is added to the oil price, adjusted for market factors*

***Assumes reduced CO_2 supply costs, 2% of oil price or $0.70 per Mcf.*

Appendix A

Using *CO_2-PROPHET* for Estimating Oil Recovery

March 2005

Model Development

The study utilized the *CO_2-PROPHET* model to calculate the incremental oil produced by CO_2-EOR from the large Illinois oil reservoirs. *CO_2-PROPHET* was developed by the Texaco Exploration and Production Technology Department (EPTD) as part of the DOE Class I cost share program. The specific project was "Post Waterflood CO_2 Flood in a Light Oil, Fluvial Dominated Deltaic Reservoir" (DOE Contract No. DE-FC22-93BC14960). *CO_2-PROPHET* was developed as an alternative to the DOE's CO_2 miscible flood predictive model, *CO_2PM*.

Input Data Requirements

The input reservoir data for operating *CO_2-PROPHET* are from the Major Oil Reservoirs Data Base. Default values exist for input fields lacking data. Key reservoir properties that directly influence oil recovery are:

- Residual oil saturation,
- Dykstra-Parsons coefficient,
- Oil and water viscosity,
- Reservoir pressure and temperature, and
- Minimum miscibility pressure.

A set of three relative permeability curves for water, CO_2 and oil are provided (or can be modified) to ensure proper operation of the model.

Calibrating CO_2-PROPHET

The *CO_2-PROPHET* model was calibrated by Advanced Resources with an industry standard reservoir simulator, *GEM*. The primary reason for the calibration was to determine the impact on oil recovery of alternative permeability distributions within a multi-layer reservoir. A second reason was to better understand how the absence of a gravity override function in *CO_2-PROPHET* might influence the calculation of oil recovery. *CO_2-PROPHET* assumes a fining upward permeability structure.

The San Joaquin Basin‘s Elk Hills (Stevens) reservoir data set was used for the calibration. The model was run in the miscible CO_2-EOR model using one hydrocarbon pore volume of CO_2 injection.

The initial comparison of *CO_2-PROPHET* with *GEM* was with fining upward and coarsening upward (opposite of fining upward) permeability cases in *GEM*. All other reservoir, fluid and operational specifications were kept the same. As Figure A-1 depicts, the *CO_2-PROPHET* output is bounded by the two *GEM* reservoir simulation cases of alternative reservoir permeability structures in an oil reservoir.

A second comparison of *CO_2-PROPHET* and *GEM* was for randomized permeability (within the reservoir modeled with multiple layers). The two *GEM* cases are High Random, where the highest permeability value is at the top of the reservoir, and Low Random, where the lowest permeability is at the top of the reservoir. The permeability values for the other reservoir layers are randomly distributed among the remaining layers. As Figure A-2 shows, the *CO_2-PROPHET* results are within the envelope of the two *GEM* reservoir simulation cases of random reservoir permeability structures in an oil reservoir.

Based on the calibration, the *CO_2-PROPHET* model seems to internally compensate for the lack of a gravity override feature and appears to provide an average calculation of oil recovery, neither overly pessimistic nor overly optimistic. As such, *CO_2-PROPHET* seems well suited for what it was designed - - providing project scoping and preliminary results to be verified with more advanced evaluation and simulation models.

Comparison of *CO_2-PROPHET* and *CO_2PM*

According to the *CO_2-PROPHET* developers, the model performs two main operations that provide a more robust calculation of oil recovery than available from *CO_2PM*:

Figure A-1. *CO2-PROPHET* and *GEM*: Comparison to Upward Fining and Coarsening Permeability Cases of *GEM*

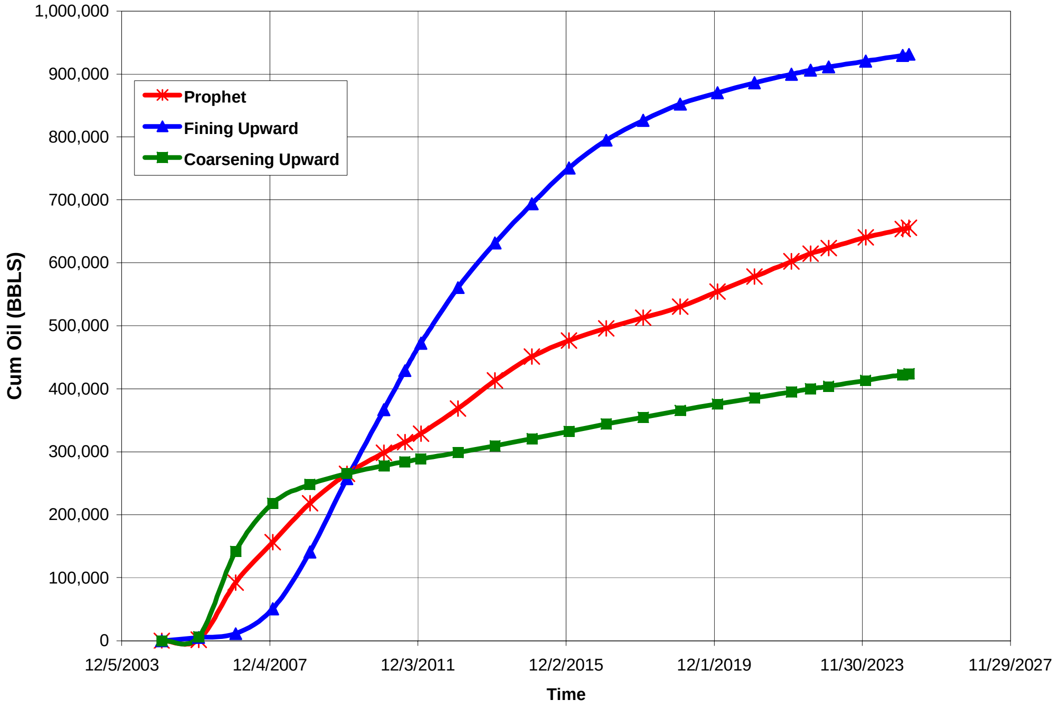
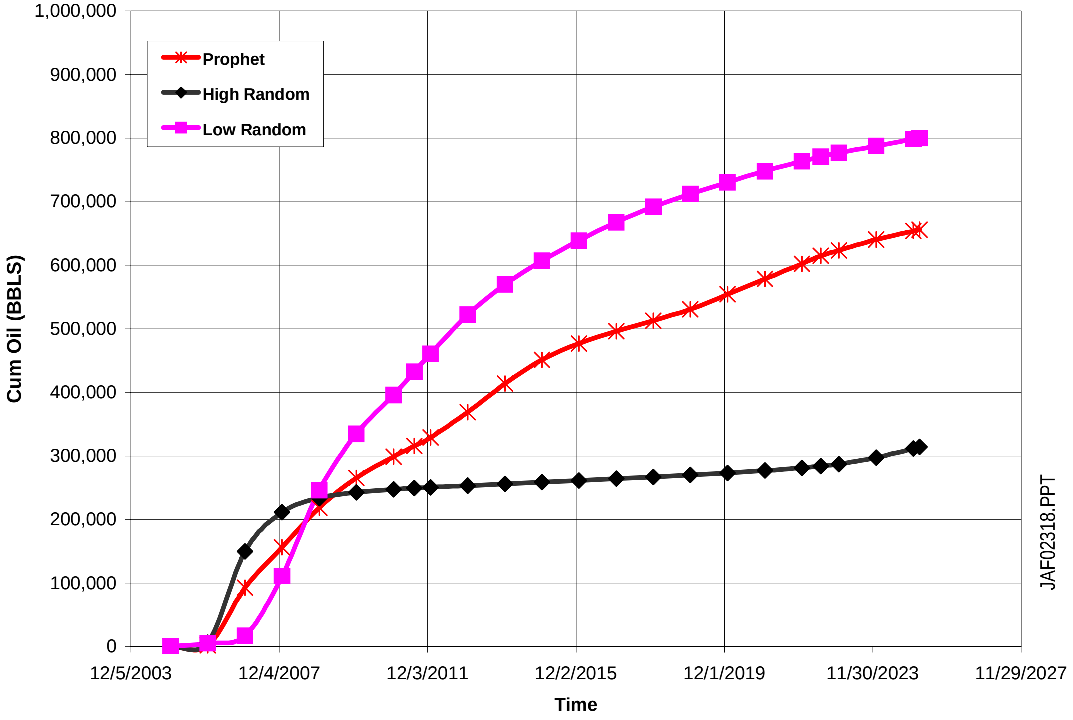


Figure A-2. CO_2-*PROPHET* and *GEM*: Comparison to Random Permeability Cases of *GEM*



- *CO_2-PROPHET* generates streamlines for fluid flow between injection and production wells, and
- The model then performs oil displacement and recovery calculations along the streamlines. (A finite difference routine is used for the oil displacement calculations.)

Other key features of *CO_2-PROPHET* and its comparison with the technical capability of *CO_2PM* are also set forth below:

- Areal sweep efficiency in *CO_2-PROPHET* is handled by incorporating streamlines that are a function of well spacing, mobility ratio and reservoir heterogeneity, thus eliminating the need for using empirical correlations, as incorporated into *CO_2PM*.
- Mixing parameters, as defined by Todd and Longstaff, are used in *CO_2-PROPHET* for simulation of the miscible CO_2 process, particularly CO_2/oil mixing and the viscous fingering of CO_2.
- A series of reservoir patterns, including 5 spot, line drive, and inverted 9 spot, among others, are available in *CO_2-PROPHET*, expanding on the 5 spot only reservoir pattern option available in *CO_2PM*.
- *CO_2-PROPHET* can simulate a variety of recovery processes, including continuous miscible CO_2, WAG miscible CO_2 and immiscible CO_2, as well as waterflooding. *CO_2PM* is limited to miscible CO_2.

Appendix B

Illinois CO_2-EOR Cost Model

March 2005

Cost Model for CO_2-Based Enhanced Oil Recovery (CO_2-EOR)

This appendix provides documentation for the cost module of the desktop CO_2-EOR policy and analytical model (COTWO) developed by Advanced Resources for DOE/FE-HQ. The sections of this cost documentation report are organized according to the normal sequence of estimating the capital and operating expenditures for a CO_2-EOR project:

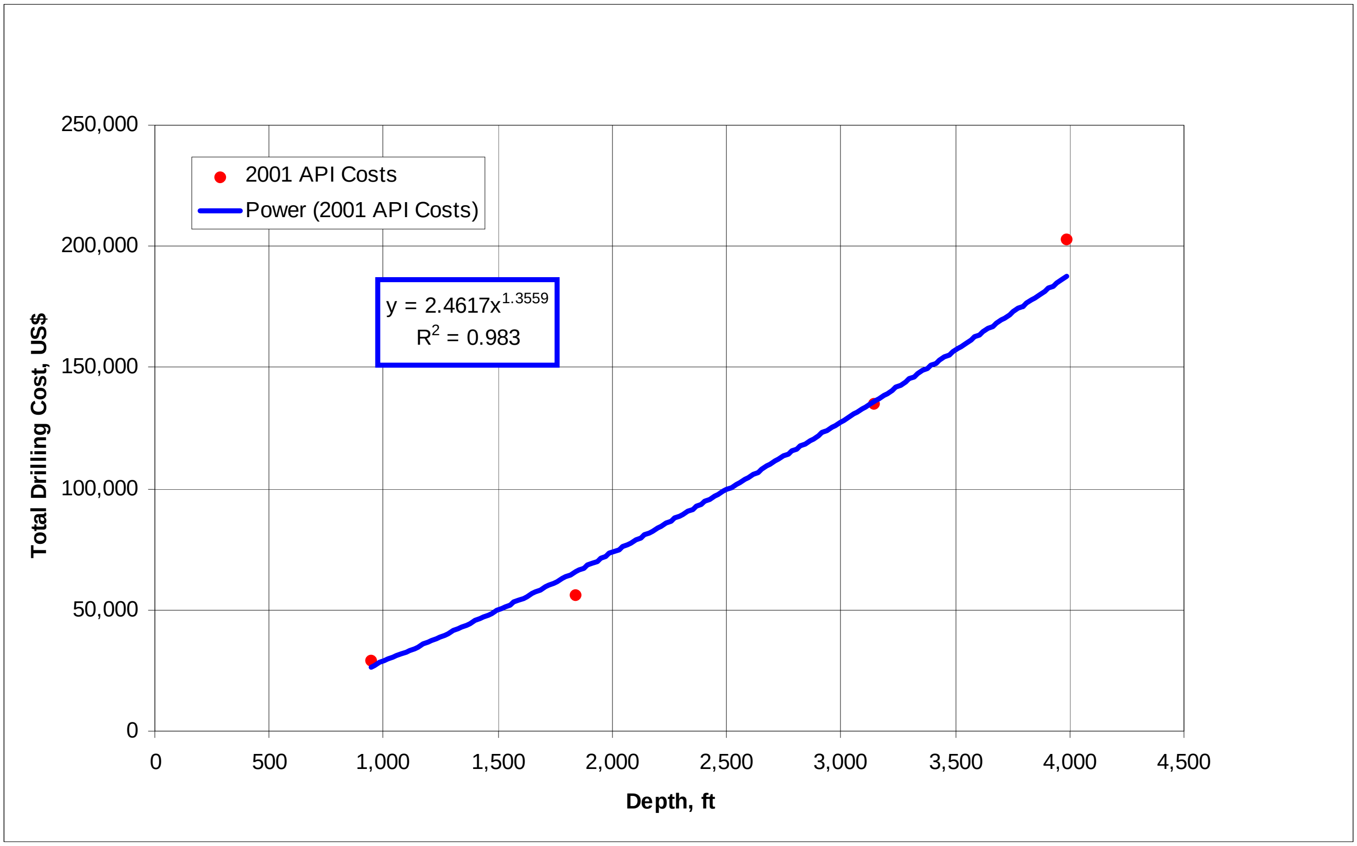
1. Well Drilling and Completion Costs. The costs for well drilling and completion (D&C) are based on the 2001 JAS cost study recently published by API for Illinois.

The well D&C cost equation has a fixed cost constant for site preparation and other fixed cost items and a variable cost equation that increases exponentially with depth. The total equation is:

Well D&C Costs = a_0D^{a1}
Where: a_0 =2.46
a_1 = 1.36
D is well depth

Figure B-1 provides the details for the cost equation and illustrates the "goodness of fit" for the well D&C cost equation for Illinois.

Figure B-1. Oil Well D&C Costs for Illinois



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****It should be noted that leasing equipment costs, reworking costs, and O&M costs from Oklahoma are used for the Illinois study, because Oklahoma is the closest state to Illinois for which Advanced Resources had reliable cost data.**

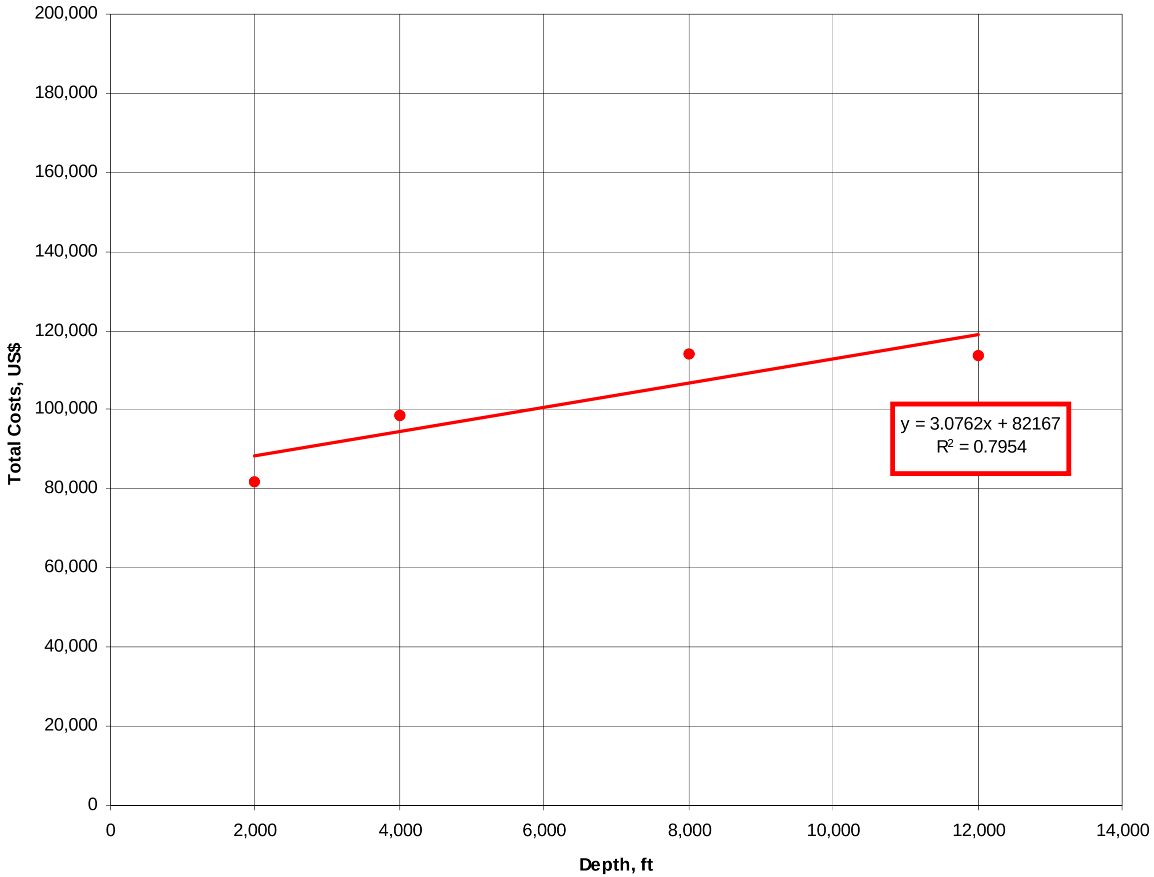
2. Lease Equipment Costs for New Producing Wells. The costs for equipping a new oil production well are based on data reported by the EIA in their 2002 EIA "Cost and Indices for Domestic Oil and Gas Field Equipment and Production Operations" report. This survey provides estimated lease equipment costs for 10 wells producing with artificial lift, from depths ranging from 2,000 to 12,000 feet, into a central tank battery.

The equation contains a fixed cost constant for common cost items, such as free water knock-out, water disposal and electrification, and a variable cost component to capture depth-related costs such as for pumping equipment. The total equation is:

Production Well Equipping Costs = $c_0 + c_1D$
Where: c_o = \$82,167 (fixed)
c_1 = \$3.08 per foot
D is well depth

Figure B-2 illustrates the application of the lease equipping cost equation for a new oil production well as a function of depth.

Figure B-2. Lease Equipping Costs for a New Oil Production Well in Illinois vs. Depth



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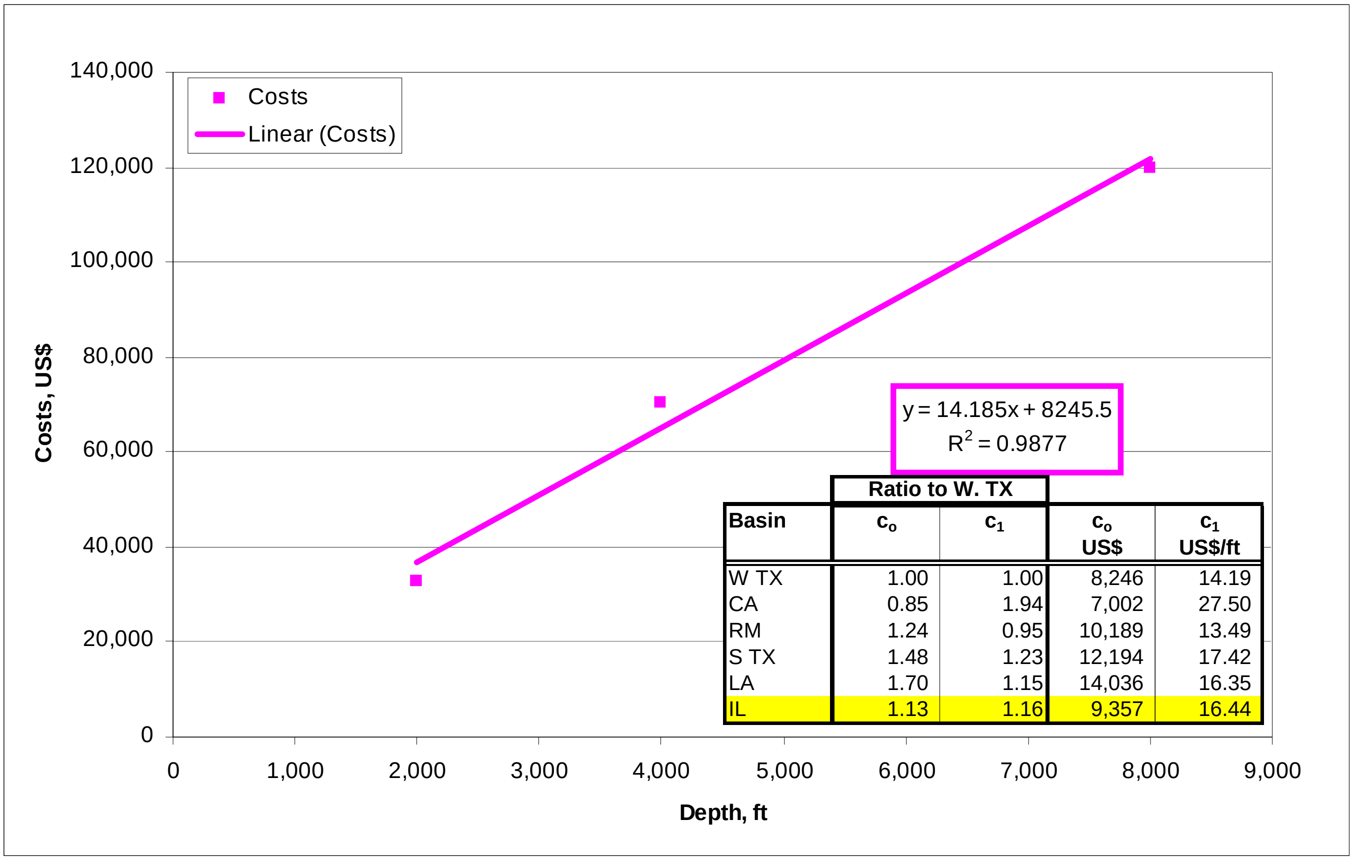
3. <u>Lease Equipment Costs for New Injection Wells.</u> The costs for equipping a new injection well in Illinois include gathering lines, a header, electrical service as well as a water pumping system. The costs are estimated from the EIA Cost and Indices Report.

Equipment costs include a fixed cost component and a depth-related cost component, which varies based on surface pressure requirements. The equation for Illinois is:

Injection Well Equipping Costs = $c_0 + c_1D$
Where: c_o = \$9,357 (fixed)
c_1 = \$16.44 per foot
D is well depth

Figure B-3 illustrates the application of the lease equipping cost equation for a new injection well as a function of depth for West Texas. The West Texas cost data for lease equipment provides the foundation for the Illinois cost equation.

Figure B-3. Lease Equipping Costs for a New Injection Well in West Texas vs. Depth



	Ratio to W. TX			
Basin	c_o	c_1	c_o US$	c_1 US$/ft
W TX	1.00	1.00	8,246	14.19
CA	0.85	1.94	7,002	27.50
RM	1.24	0.95	10,189	13.49
S TX	1.48	1.23	12,194	17.42
LA	1.70	1.15	14,036	16.35
IL	1.13	1.16	9,357	16.44

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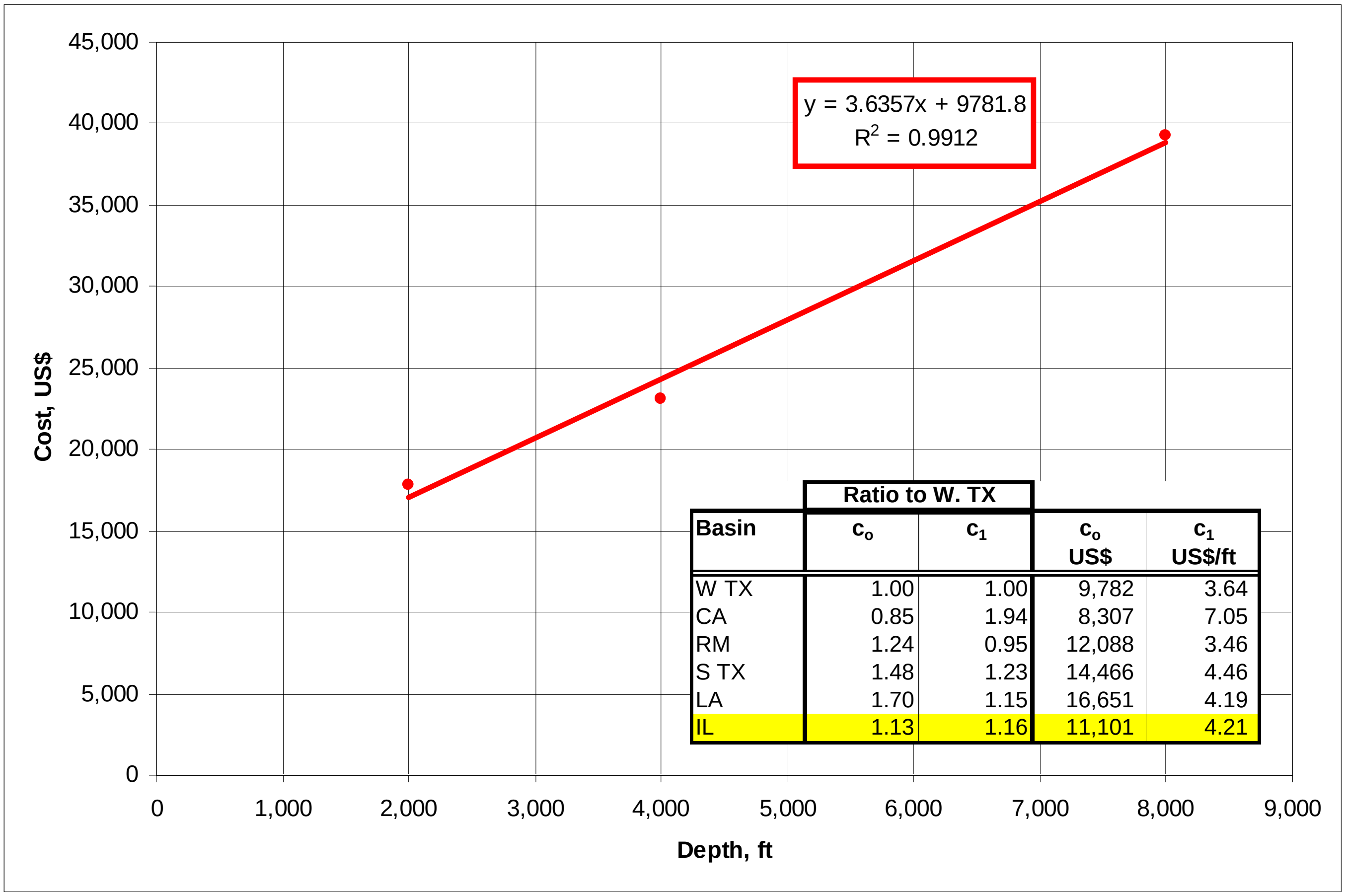
4. Converting Existing Production Wells into Injection Wells. The conversion of existing oil production wells into CO_2 and water injection wells requires replacing the tubing string and adding distribution lines and headers. The costs assume that all surface equipment necessary for water injection are already in place on the lease.

The existing well conversion costs include a fixed cost component and a depth-related cost component, which varies based on the required surface pressure and tubing length. The equation for Illinois is:

Well Conversion Costs = $c_0 + c_1 D$
Where: c_o = \$11,101 (fixed)
c_1 = \$4.21 per foot
D is well depth

Figure B-4 illustrates the average cost of converting an existing producer into an injection well for West Texas. The West Texas cost data for converting wells provide the foundation for the Illinois cost equation.

Figure B-4. Cost of Converting Existing Productions Wells into Injection Wells in West Texas vs. Depth



	Ratio to W. TX			
Basin	**c_o**	**c_1**	**c_o US\$**	**c_1 US\$/ft**
W TX	1.00	1.00	9,782	3.64
CA	0.85	1.94	8,307	7.05
RM	1.24	0.95	12,088	3.46
S TX	1.48	1.23	14,466	4.46
LA	1.70	1.15	16,651	4.19
IL	1.13	1.16	11,101	4.21

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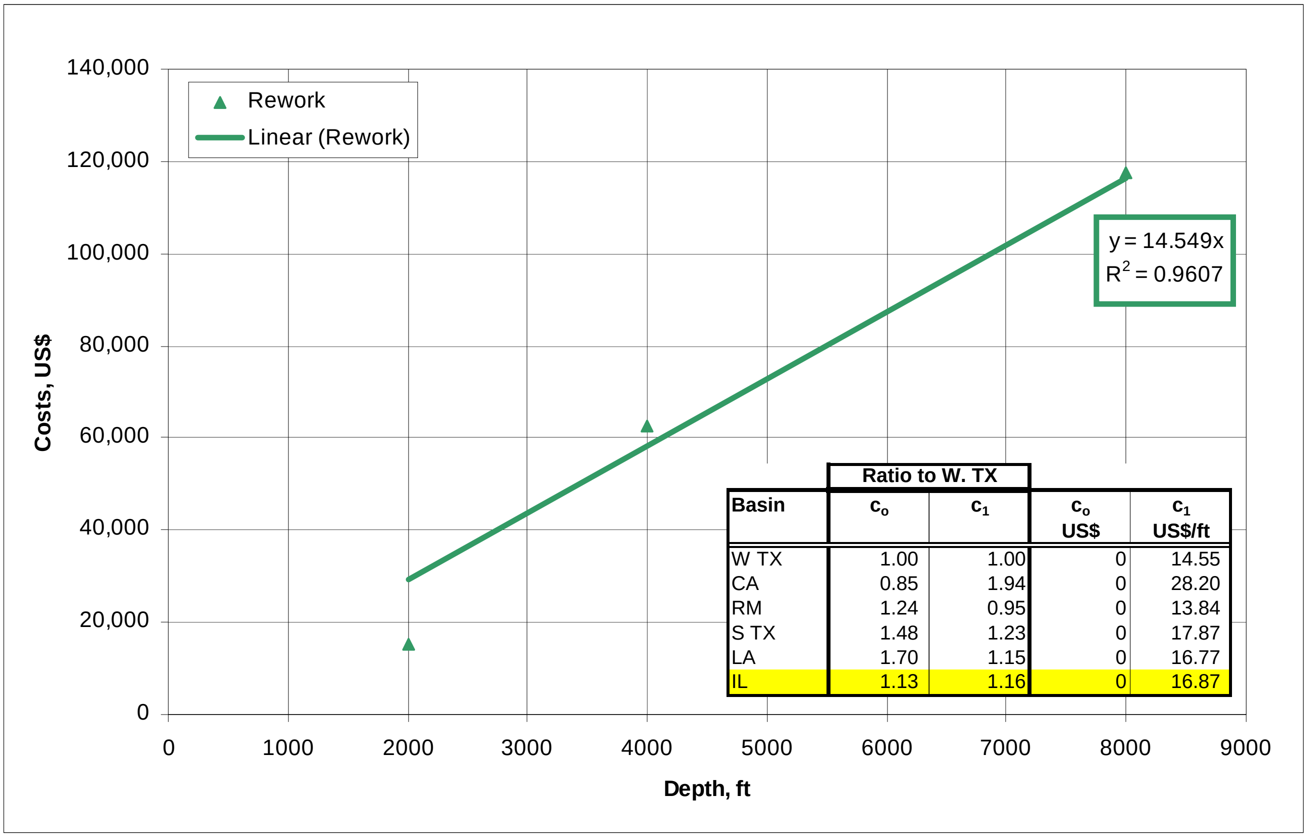
5. Costs of Reworking an Existing Waterflood Production or Injection Well for CO_2-EOR (First Rework). The reworking of existing oil production or CO_2-EOR injection wells requires pulling and replacing the tubing string and pumping equipment. The well reworking costs are depth-dependent. The equation for Illinois is:

Well Rework Costs = c_1D
Where: c_1 = \$28.20 per foot)
D is well depth

Figure B-5 illustrates the average cost of well conversion as a function of depth for West Texas. The West Texas cost data for reworking wells provides the foundation for the Illinois cost equation.

Figure B-5. Cost of Reworking an Existing Waterflood Production or Injection Well for CO_2-EOR in West Texas vs. Depth



Basin	Ratio to W. TX c_o	 c_1	c_o US$	c_1 US$/ft
W TX	1.00	1.00	0	14.55
CA	0.85	1.94	0	28.20
RM	1.24	0.95	0	13.84
S TX	1.48	1.23	0	17.87
LA	1.70	1.15	0	16.77
IL	1.13	1.16	0	16.87

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6. <u>Annual O&M Costs, Including Periodic Well Workovers.</u> The EIA Cost and Indices report provides secondary operating and maintenance (O&M) costs only for West Texas. As such, West Texas and Illinois primary oil production O&M costs (Figure B-6) are used to estimate Illinois secondary recovery O&M costs. Linear trends are used to identify fixed cost constants and variable cost constants for each region, Table B-1.

Figure B-6. Annual Lease O&M Costs for Primary Oil Production by Area

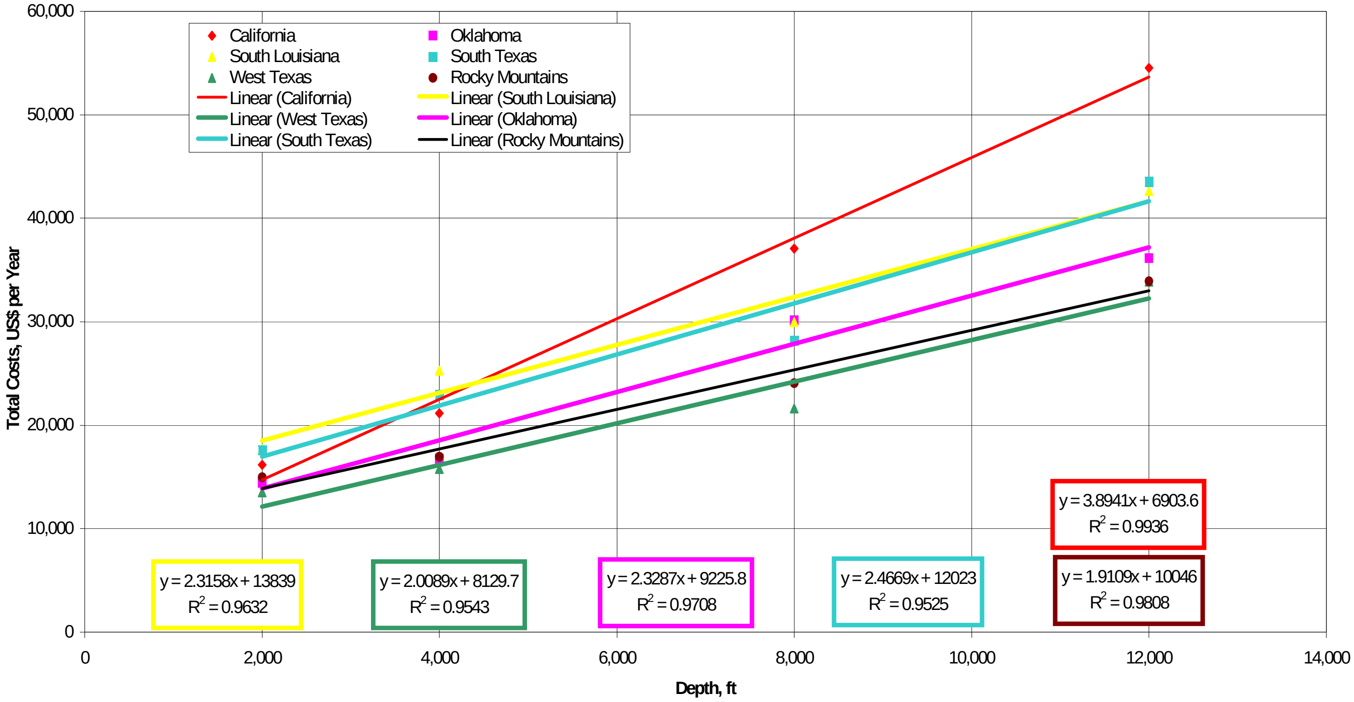

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Table B-1. Regional Lease O&M Costs and Their Relationship to West Texas

			Ratio to W. TX	
Basin	**c_o US$**	**c_1 US$/ft**	**c_o**	**c_1**
West Texas	8,130	2.01	1.00	1.00
California	6,904	3.89	0.85	1.94
Rocky Mountain	10,046	1.91	1.24	0.95
South Texas	12,023	2.47	1.48	1.23
Louisiana	13,839	2.32	1.70	1.15
Illinois	9,226	2.33	1.13	1.16

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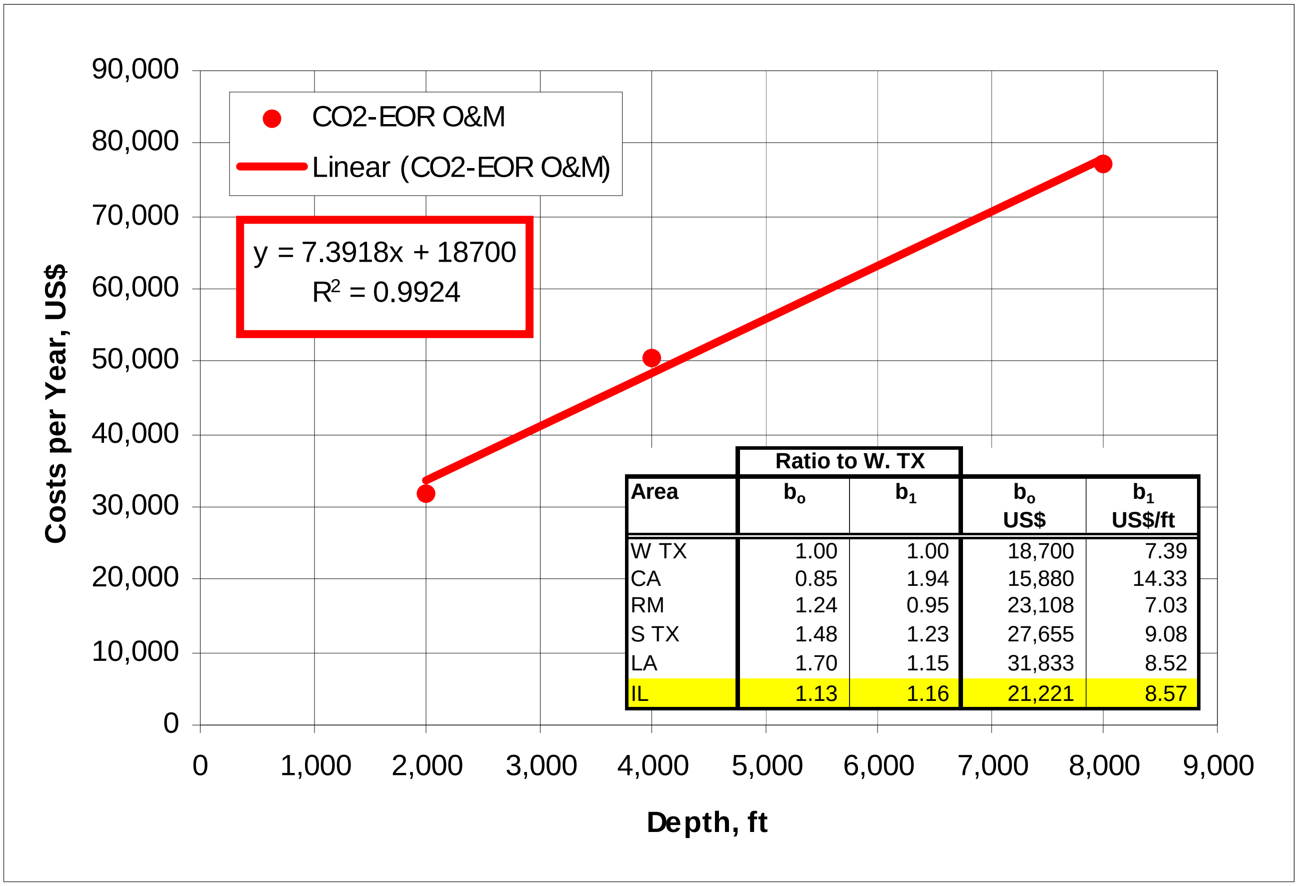
To account for the O&M cost differences between waterflooding and CO_2-EOR, two adjustments are made to the EIA's reported O&M costs for secondary recovery. Workover costs, reported as surface and subsurface maintenance, are doubled to reflect the need for more frequent remedial well work in CO_2-EOR projects. Liquid lifting is subtracted from annual waterflood O&M costs to allow for the more rigorous accounting of liquid lifting volumes and costs for CO_2-EOR. (Liquid lifting costs for CO_2-EOR are discussed in a later section of this appendix.)

Figure B-7 shows the depth-relationship for CO_2-EOR O&M costs in West Texas. These costs were adjusted to develop O&M for Illinois, shown in the inset of Figure B-7. The equation for Illinois is:

Well O&M Costs = $b_0 + b_1D$
Where: b_0 = \$21,221 (fixed)
b_1 = \$8.57 per foot
D is well depth

Figure B-7. Annual CO_2-EOR O&M Costs for West Texas



	Ratio to W. TX			
Area	**b_o**	**b_1**	**b_o US\$**	**b_1 US\$/ft**
W TX	1.00	1.00	18,700	7.39
CA	0.85	1.94	15,880	14.33
RM	1.24	0.95	23,108	7.03
S TX	1.48	1.23	27,655	9.08
LA	1.70	1.15	31,833	8.52
IL	1.13	1.16	21,221	8.57

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7. CO_2 Recycle Plant Investment Cost. Operation of CO_2-EOR requires a recycling plant to capture and reinject the produced CO_2. The size of the recycling plant is based on peak CO_2 production and recycling requirements.

The cost of the recycling plant is set at $700,000 per MMcfd of CO_2 capacity. As such, a small CO_2-EOR project in the St. Louis formation of the Clay City Consolidated field, with 16 MMcfd of CO_2 reinjection, will require a recycling plant costing $10.9 million. A large project in the Aux Vases formation of the Dale City field, with 73 MMcfd of CO_2 reinjection and 138 injectors, requires a recycling plant costing $51.4 million.

The model has three options for installing a CO_2 recycling plant. The default setting costs the entire plant one year prior to CO_2 breakthrough. The second option places the full CO_2 recycle plant cost at the beginning of the project (Year 0). The third option installs the CO_2 recycle plant in stages. In this case, half the plant is built (and half the cost is incurred) in the year of CO_2 breakthrough. The second half of the plant is built when maximum recycle capacity requirements are reached.

8. Other GOTWO Model Costs.

a. CO_2 Recycle O&M Costs. The O&M costs of CO_2 recycling are indexed to energy costs and set at 1% of the oil price ($0.25 per Mcf @ $25 Bbl oil).

b. Lifting Costs. Liquid (oil and water) lifting costs are calculated on total liquid production and costed at $0.25 per barrel. This cost includes liquid lifting, transportation and re-injection.

c. CO_2 Distribution Costs. The CO_2 distribution system is similar to the gathering systems used for natural gas. A distribution "hub" is constructed with smaller pipelines delivering purchased CO_2 to the project site.

The distribution pipeline cost is dependent on the injection requirements for the project. The fixed component is $150,000. The variable cost component accounts for increasing piping diameters associated with increasing CO_2 injection requirements. These range from $80,000 per mile for 4" pipe (CO_2 rate less than 15MMcfd), $120,000 per mile for 6" pipe (CO_2 rate of 15 to 35 MMcfd), $160,000 per mile for 8" pipe (CO_2 rate of 35 to 60 MMcfd), and $200,000 per mile for pipe greater than 8" diameter (CO_2 rate greater than 60 MMcfd). Aside from the injection volume, costs also depend on the distance from the CO_2 "hub" (transfer point) to the oil field. Currently, the distance is set at 10 miles.

The CO_2 distribution cost equation for Illinois is:

Pipeline Construction Costs = \$150,000 + C_D*Distance
Where: C_D is the cost per mile of the necessary pipe diameter (from the CO_2 injection rate)
Distance = 10.0 miles

d. G&A Costs. General and administrative (G&A) costs of 20% are added to well O&M and lifting costs.

e. Royalties. Royalty payments are assumed to be 12.5%.

f. Production Taxes. Severance and ad valorum taxes are both set at 0% on the oil production stream.

g. Crude Oil Price Differential. To account for market and oil quality (gravity) differences on the realized oil price, the cost model incorporated the current basis differential for Illinois (\$(1.00) per barrel) and the current gravity differential (-\$0.25 per ^{o}API, from a basis of 40 ^{o}API) into the average wellhead oil price realized by each oil reservoir. The equation for Illinois is:

Wellhead Oil Price = Oil Price + \$(1.00) – [\$0.25*(40 - ^{o}API)]
Where: Oil Price is the marker oil price (West Texas Intermediate)
^{o}API is oil gravity

If the oil gravity is less than 40 ^{o}API, the wellhead oil price is reduced; if the oil gravity is greater than 40 ^{o}API, the wellhead oil price is increased.