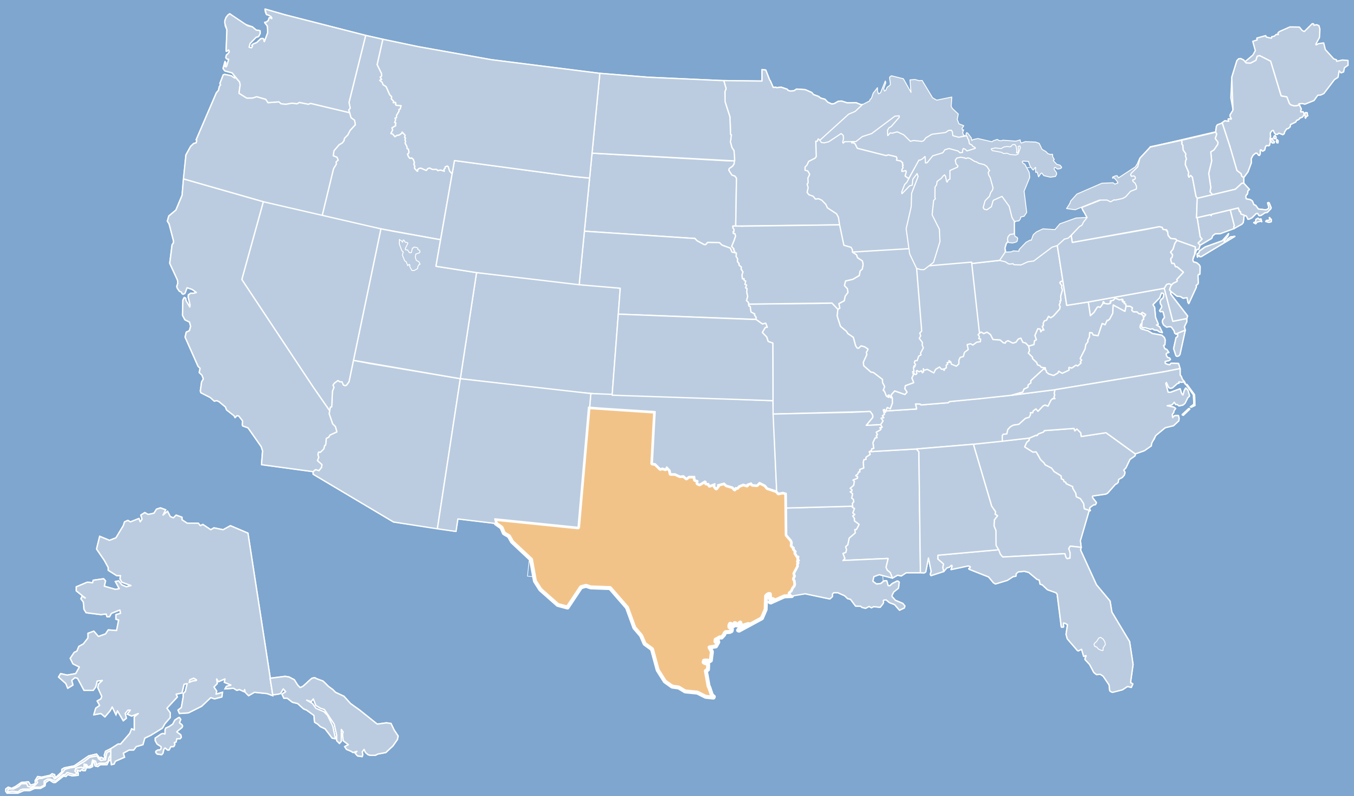
Basin Oriented Strategies for CO_2 Enhanced Oil Recovery:

EAST & CENTRAL TEXAS



Prepared for
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Prepared by
Advanced Resources International

February 2006

BASIN ORIENTED STRATEGIES FOR CO_2 ENHANCED OIL RECOVERY: EAST AND CENTRAL TEXAS

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1. SUMMARY OF FINDINGS

***1.1 INTRODUCTION**.* The oil and gas producing regions of East and Central Texas have nearly 74 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 mature reservoirs that appear to be 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 East and Central Texas 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 Texas' oil production industry overcome these barriers and capture the large "stranded oil" prize.

1.2 ALTERNATIVE OIL RECOVERY STRATEGIES AND SCENARIOS. The report sets forth four scenarios for using CO_2-EOR to recover "stranded oil" in East and Central Texas.

- 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 recent years, is successfully applied in Texas. In addition, this scenario assumes that a comprehensive program of research, pilot tests and field demonstrations help lower the risks inherent in applying new technology to these complex Texas oil reservoirs.

- The third scenario, entitled "Risk Mitigation," examines how the economic potential of CO_2-EOR could be increased through a strategy involving state production tax reductions, federal investment tax credits, royalty relief and/or higher world oil prices that together would add an equivalent $10 per barrel to the price that the producer uses for making capital investment decisions for CO_2-EOR.
- The final scenario, entitled "Ample Supplies of CO_2," examines low-cost, "EOR-ready" CO_2 supplies are aggregated from various industrial and natural sources. These include industrial high-concentration CO_2 emissions from hydrogen facilities, gas processing plants, chemical plants and other sources in the region. These would be augmented, in the longer-term, from low concentration CO_2 emissions from refineries and electric power plants. Capture of industrial CO_2 emissions could also be part of a national effort for reducing greenhouse gas emissions.

The CO_2-EOR potential of East and Central Texas is examined using these four bounding scenarios.

1.3 OVERVIEW OF FINDINGS. Eleven major findings emerge from the study of "Basin Oriented Strategies for CO_2 Enhanced Oil Recovery: East and Central Texas."

1. Today's oil recovery practices will leave behind a large resource of "stranded oil" in East and Central Texas. The original oil resource in East and Central Texas reservoirs is estimated at 109 billion barrels. To date, over 35 billion barrels of this original oil in-place (OOIP) has been recovered or proved. Thus, without further oil recovery methods, nearly 74 billion barrels of East and Central Texas oil resource will become "stranded", Table 1.

Table 1. East and Central Texas Oil Resource and Reservoirs

State	No. of Reservoirs	OOIP (Billion Bbls)	Cumulative Recovery/ Reserves (Billion Bbls)	ROIP (Billion Bbls)
A. Major Oil Reservoirs				
Central Texas*	61	24.7	5.7	19.0
East Texas**	21	20.0	8.1	11.9
Texas Gulf Coast***	117	23.0	9.1	13.9
Data Base Total	199	67.7	22.9	44.8
*B. Regional Total*** **	N/A	108.0	35.4	72.6

** Includes RR Districts #1, #7B, #7C, #9 and #10.*
*** Includes RR Districts #5 and #6.*
**** Includes RR Districts #2, #3 and #4.*
*****Estimated from Texas data on cumulative oil recovery and proved reserves, as of the end of 2002.*

2. A major portion of the "stranded oil" resource in the large oil reservoirs of East and Central Texas is amenable to CO_2 enhanced oil recovery. To address the "stranded oil" issue, Advanced Resources assembled a data base that contains 199 major East and Central Texas oil reservoirs, accounting for 65% of the region's estimated ultimate oil production. Of these, 161 reservoirs, with 53 billion barrels of OOIP and 34 billion barrels of "stranded oil" (ROIP), were found to be favorable for CO_2-EOR, Table 2.

Table 2. East and Central Texas "Stranded Oil" Resources Amenable to CO_2-EOR

State	No. of Reservoirs	OOIP (Billion Bbls)	Cumulative Recovery/ Reserves (Billion Bbls)	ROIP (Billion Bbls)
Central Texas	42	13.2	2.9	10.3
East Texas	16	18.5	7.5	11.0
Texas Gulf Coast	103	21.5	8.7	12.8
TOTAL	161	53.2	19.1	34.1

3. Application of miscible CO_2-EOR would enable a significant portion of the "stranded oil" in East and Central Texas to be recovered. Of the 161 large East and Central Texas oil reservoirs (with 53 billion barrels OOIP), 145 screen as being favorable for miscible CO_2-EOR, leaving 16 of the reservoirs for development by the less efficient CO_2 immiscible process. The technically recoverable resource from applying miscible and immiscible CO_2-EOR in these 161 large oil reservoirs ranges from 4,620 million barrels to 10,960 million barrels, Table 3.

Table 3. Technically Recoverable Resource from East and Central Texas Using Miscible CO_2-EOR

State	Miscible		Immiscible	
	No. of Reservoirs	Technically Recoverable* (MMBbls)	No. of Reservoirs	Technically Recoverable* (MMBbls)
Central Texas	42	1,560 – 3,370	0	0
East Texas	10	1,280 – 2,820	6	0 – 680
Texas Gulf Coast	93	1,780 – 3,960	10	0 – 140
TOTAL	145	4,620 - 10,140	16	0 - 820

**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, very little of the "stranded oil" in East and Central Texas will become economically recoverable. As shown above, traditional application of miscible CO_2-EOR technology (involving a relatively modest volume of CO_2 injection) to the 145 large reservoirs in the data base would enable 4.6 billion barrels of "stranded oil" to become technically recoverable. With current costs for CO_2 (equal to $1.50 per Mcf) and a substantial risk premium, because of uncertainties about future oil prices and the performance of CO_2-EOR technology, only 1.6 billion barrels of this "stranded oil" could become economically recoverable at oil prices of $30 per barrel, as adjusted for gravity and location, Table 4.

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

State	No. of Reservoirs	OOIP (MMBbls)	Technically Recoverable (MMBbls)	Economically* Recoverable (MMBbls)
Central Texas	42	13,172	1,560	160
East Texas	10	13,971	1,280	1,120
Texas Gulf Coast	93	20,159	1,780	360
TOTAL	145	47,302	4,620	1,640

This case assumes an oil price of $30 per barrel, a CO_2 cost of $1.50 per Mcf, and a ROR hurdle rate of 25% (before tax).

5. Introduction of "State-of-the-art" CO_2-EOR technology, risk mitigation incentives and lower CO_2 costs would enable 8.6 billion barrels of additional oil to become economically recoverable from East and Central Texas. With "State-of-the-art" CO_2-EOR technology, and its higher oil recovery efficiency (at oil prices of $30/B and high cost CO_2), 7.3 billion barrels of the oil remaining in the large oil reservoirs of East and Central Texas becomes economically recoverable under Scenario #2.

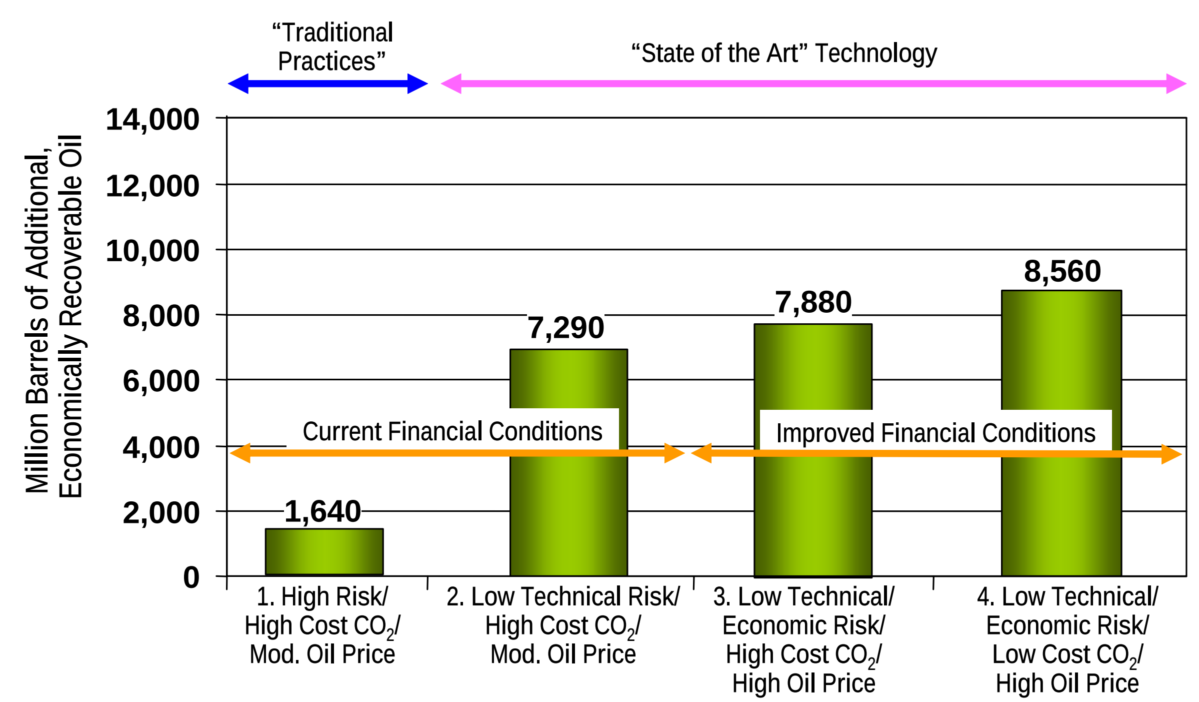
Risk mitigation incentives and/or higher oil prices, providing an oil price equal to $40 per barrel, would enable 7.9 billion barrels of oil to become economically recoverable from the large oil reservoirs in East and Central Texas under Scenario #3.

Lower cost CO_2 supplies, equal to $0.80 per Mcf at $40 a barrel and assuming a large-scale CO_2 transportation system and incentives for of CO_2 capture emissions, would enable the economic potential to increase to 8.6 billion barrels under Scenario #4, Table 5 and Figure 1.

Table 5. Economically Recoverable Resources — Alternative Scenarios

Basin	Scenario #2: "State-of-the-art" (Moderate Oil Price/ High CO_2 Cost)		Scenario #3: "Risk Mitigation" (High Oil Price/ High CO_2 Cost)		Scenario #4: "Ample Supplies of CO_2" (High Oil Price/ Low CO_2 Cost)	
	(# Reservoirs)	(MMBbls)	(# Reservoirs)	(MMBbls)	(# Reservoirs)	(MMBbls)
Central Texas	22	1,260	22	1,260	24	1,330
East Texas	12	3,350	13	3,480	13	3,480
Texas Gulf Coast	58	2,680	70	3,140	91	3,750
TOTAL	92	7,290	104	7,880	128	8,560

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



1. This case assumes an oil price of \$30 per barrel, a CO_2 cost of \$1.50/Mcf and a ROR hurdle rate of 25% (before tax).
2. This case assumes an oil price of \$30 per barrel, a CO_2 cost of \$1.50/Mcf and a ROR hurdle rate of 15% (before tax).
3. This case assumes an oil price of \$40 per barrel, a CO_2 cost of \$2.00/Mcf and a ROR hurdle rate of 15% (before tax).
4. This case assumes an oil price of \$40 per barrel, a CO_2 cost of \$0.80/Mcf and a ROR hurdle rate of 15% (before tax).

6. Once the results from the study's large oil reservoirs data base are extrapolated to the state as a whole, the technically recoverable CO_2-EOR potential for East and Central Texas is estimated at over 17 billion barrels. The large East and Central Texas oil reservoirs examined by the study account for 65% of the region's oil resource. Extrapolating the 11.0 billion barrels of technically recoverable EOR potential in these 165 oil reservoirs to the total East and Central Texas oil resource provides an estimate of 17.3 billion barrels of technical CO_2-EOR potential. (However, no extrapolation of economic potential has been estimated, as the development costs of the 165 large East and Central Texas 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 East and Central Texas will, most likely, prove to be higher than defined by this study. Introduction of more advanced "next generation" 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 and mobility control agents, could significantly increase recoverable oil volumes. These "next generation" technologies would also expand the state's geologic capacity for storing CO_2 emissions.

8. Large volumes of CO_2 supplies will be required in East and Central Texas to achieve the CO_2-EOR potential defined by this study. The overall market for purchased CO_2 could be up to 31 Tcf, plus another 67 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 the East and Central Texas oil reservoirs would enable over 1.5 billion metric 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 East and Central Texas:
Scenario #4 ("Ample Supplies of CO_2")

Region	No. of Reservoirs	Economically Recoverable* (MMBbls)	Purchased CO_2 (Bcf)	Recycled CO_2 (Bcf)
Central Texas	24	1,330	5,300	10,940
East Texas	13	3,480	10,880	23,680
Texas Gulf Coast	91	3,750	14,720	32,250
TOTAL	128	8,560	30,900	66,870

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

9. Significant supplies of both natural and industrial CO_2 emissions exist in or near East and Central Texas, sufficient to meet the CO_2 needs for EOR. The natural CO_2 deposits at McElmo Dome (CO), Bravo Dome (NM), and Sheep Mountain Dome (CO) are estimated to hold upwards of 20 Tcf of recoverable CO_2. These sources could, with extention of pipeline, deliver CO2 to Central Texas. CO_2 emissions, from gas processing plants and hydrogen plants in the region (estimated at 384 MMcf/d), could provide additional high concentration (relatively low cost) CO_2. Finally, large supplies of low concentration CO_2 emissions would be available from the large power plants and refineries in the region, assuming affordable cost CO_2 capture technology is developed.

10. A public-private partnership will be required to overcome the many barriers facing large scale application of CO_2-EOR in East and Central Texas 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 many of the smaller 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 state of Texas and the federal government will be needed to overcome these barriers.

11. Many entities will share in the benefits of increased CO_2-EOR based oil production in East and Central Texas. Successful introduction and wide-scale use of CO_2-EOR in East and Central Texas will stimulate increased economic activity, provide new higher paying jobs, and lead to higher tax revenues for the state. It will help revive 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 Texas. Specifically, we would like to thank Steve Melzer for his invaluable assistance in compiling this report. In addition we would like to acknowledge the prior work by the Texas Bureau of Economic Geology on the potential for CO_2-EOR in Texas which provides a basis for comparison with our results.

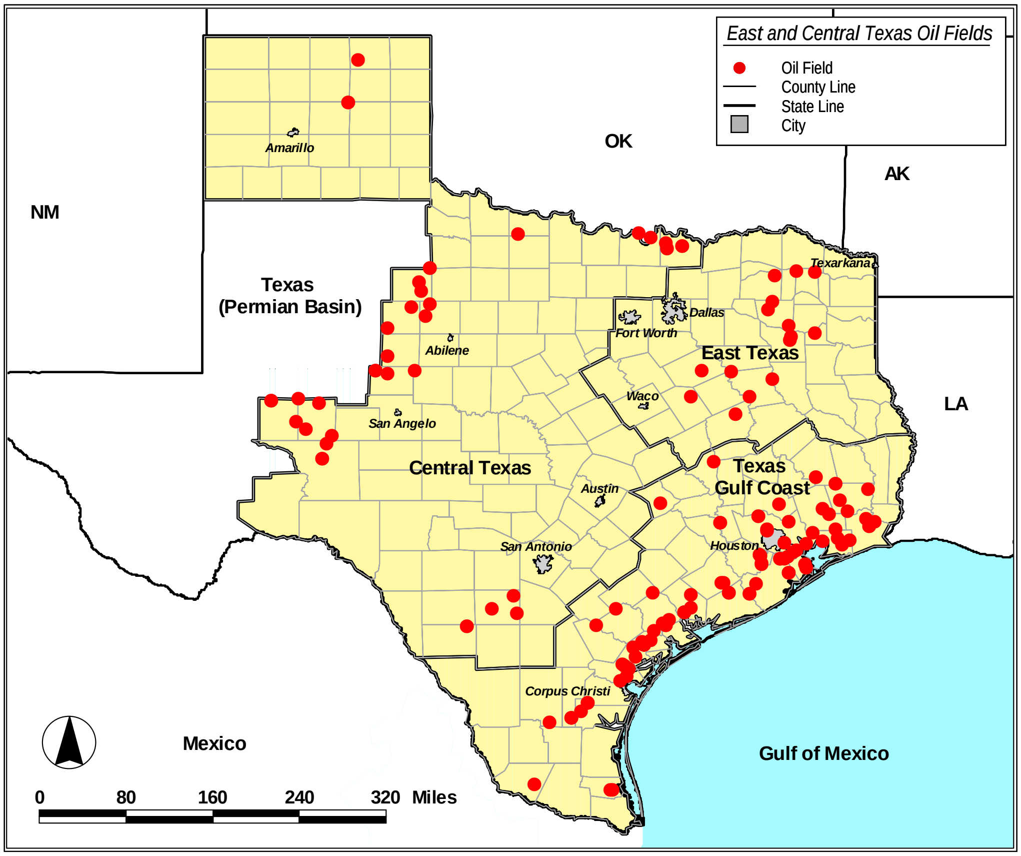
2. INTRODUCTION

2.1 CURRENT SITUATION. East and Central Texas contains numerous old or abandoned oil fields, and those that are still active are considered mature and in decline. Oil production in East and Central Texas (all Railroad Districts except #8 and #8A) peaked in the early 1950's and 1970's at just over 670 MMBbls and has seen a steady decline since that time, despite widespread implementation of secondary oil recovery projects as well as a handful of tertiary recovery projects. The main purpose of this report is to provide information on the potential for pursuing increased CO_2 enhanced oil recovery (CO_2-EOR) as one option for slowing or potentially stopping the decline in oil production.

This report, "Basin Oriented Strategies for CO_2 Enhanced Oil Recovery: East and Central Texas," provides information on the size of the technical and economic potential for CO_2-EOR in the East and Central Texas oil producing regions. 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 more advanced methods of CO_2-EOR. (The CO_2-EOR potential in West Texas (RR Districts #8 and #8A) is addressed in a separate report entitled "Basin Oriented Strategies for CO_2 Enhanced Oil Recovery: Permian Basin.")

2.2 BACKGROUND. East and Central Texas is one of the largest oil producing regions in the country. After experiencing severe declines in crude oil reserves and production capacity, the east and central portions of Texas are currently producing 324 thousand barrels of oil per day. However, the deep, light oil reservoirs of this region are ideal candidates for miscible carbon dioxide-based enhanced oil recovery (CO_2-EOR), much like those in the Permian Basin. The East and Central Texas oil producing regions and the concentration of its major oil reservoirs are shown in Figure 2.

Figure 2. Locations of Major East and Central Texas Oil Fields Amenable to CO_2-EOR



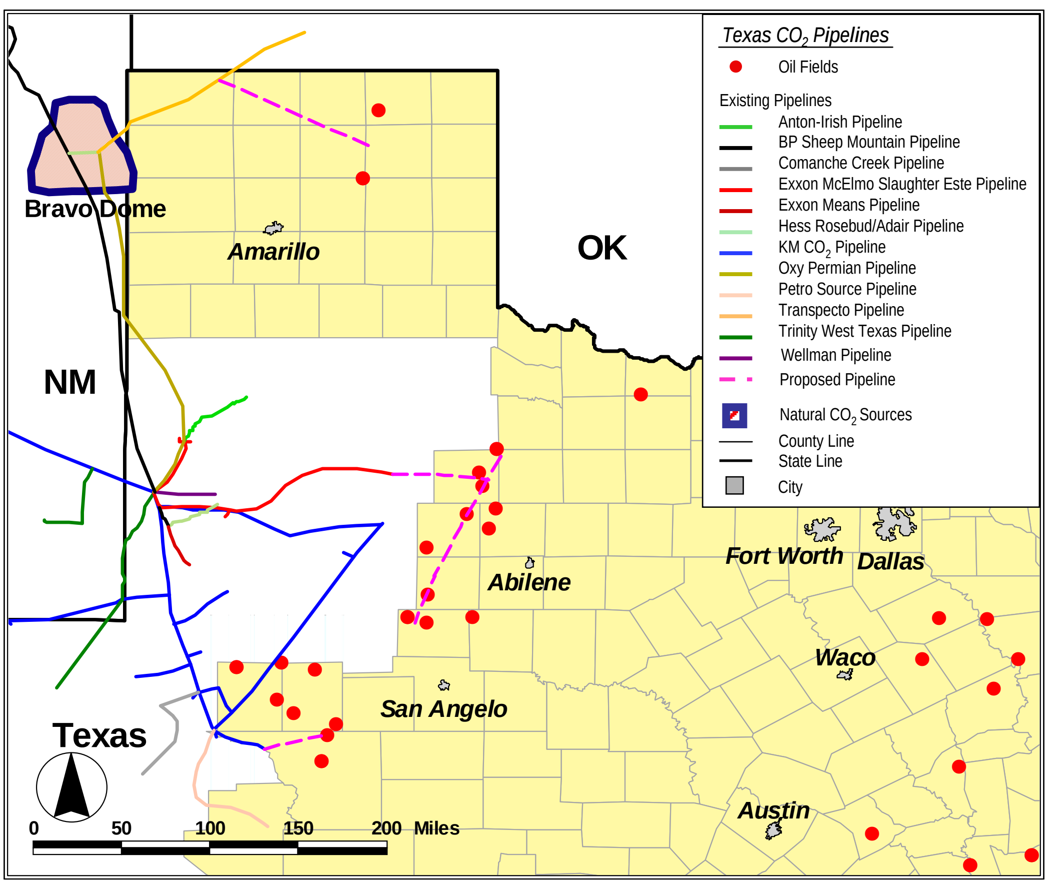
2.3 PURPOSE. This report, "Basin Oriented Strategies for CO_2 Enhanced Oil Recovery: East and Central Texas" is part of a larger effort to examine the enhanced oil recovery and CO_2 storage potential in key U.S. oil basins. The work involves establishing the geological and reservoir characteristics of 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, examining the economic feasibility of applying CO_2-EOR. The aim of this report is to provide information that could assist: (1) formulating 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.

An additional important purpose of the study is to develop a desktop modeling and analytical capability for "basin oriented strategies" that would enable the

Department of Energy/Fossil Energy (DOE/FE) itself 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.

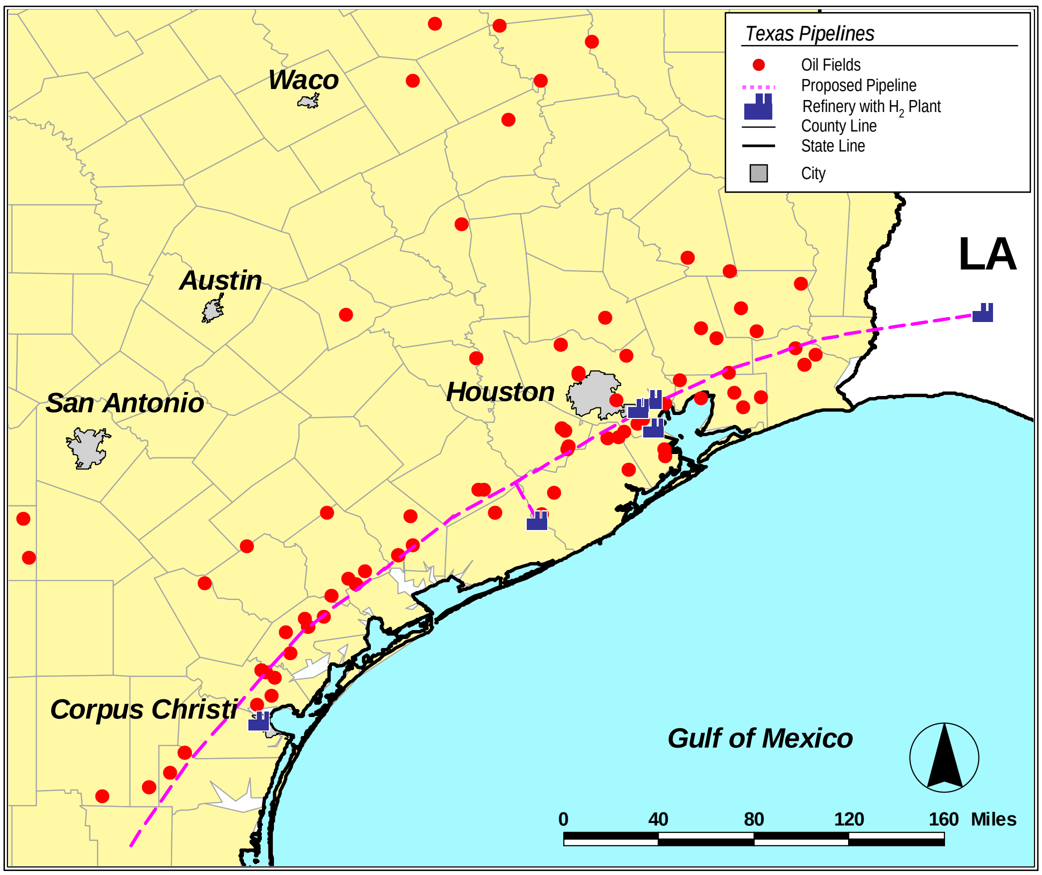
2.4 KEY ASSUMPTIONS. For purposes of this study, it is assumed that sufficient supplies of CO_2 are available, from extension of pipelines in the Permian Basin delivering CO_2 from natural sources in Colorado and New Mexico, or from anthropogenic sources such as the refineries along the Gulf Coast. Figure 3 shows the existing pipeline system that transports CO_2 from the natural CO_2 reservoirs at McElmo, Bravo, and Sheep Mountain Domes to the oil fields of the Permian Basin. It also shows the proposed extensions of these pipeline systems to the oil fields of central Texas.

Figure 3. Existing CO_2 Pipelines and Proposed Extensions to Central Texas



In addition, the oil fields in East Texas are near major oil refineries, hydrogen plants, and other anthropogenic industrial sources along the Gulf Coast of Texas and Louisiana. Figure 4 shows a possible network of pipelines connecting the industrial CO_2 sources in the Gulf Coast region to the oil producing areas of East Texas.

Figure 4. Potential CO_2 Pipelines in Eastern Texas



2.5 TECHNICAL OBJECTIVES. The objectives of this study are to examine the technical and the economic potential of applying CO2-EOR in East and Central Texas oil reservoirs, 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).

2. *"State-of-the-art" Technology*. This involves applying the recent improvements in the performance of CO_2-EOR process and gains in understanding of 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". 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 hydrocarbon components into the CO_2 phase and solution of CO_2 in the oil phase) with the oil remaining in the reservoir. Typically, reservoirs at depths greater than 3,000 feet and with oil gravities greater than 25 ^{o}API would be selected for miscible CO_2-EOR. Major Texas light oil fields such as Giddings, Tom O'Connor, and Spraberry

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*. These are the moderately heavy oil reservoirs (as well as shallower light oil reservoirs) that do not meet the stringent requirements for miscibility (shallower than 3,000 ft or having oil gravities between 17.5^o and 25 ^{o}API). In this study, there were 16 East and Central Texas oil reservoirs that were considered for immiscible flooding.

Combining the technology and oil reservoir options, the following oil reservoir and CO_2 flooding technology matching is applied to the East and Central Texas reservoirs amenable to CO_2-EOR, Table 7.

Table 7. Matching of CO_2-EOR Technology with East and Central Texas Oil Reservoirs

CO_2-EOR Technology Selection	Oil Reservoir Selection
"Traditional Practices"; Miscible CO_2-EOR	▪ 145 Deep, Light Oil Reservoirs
"State of the Art"; Miscible and Immiscible CO_2-EOR	▪ 145 Deep, Light Oil Reservoirs ▪ 16 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 East and Central Texas's major oil reservoirs. Because of confidentiality and proprietary issues, 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 results reported in this study.

3. OVERVIEW OF TEXAS OIL PRODUCTION

3.1 HISTORY OF OIL PRODUCTION. East and Central Texas is one of the largest oil producing, and intensively explored and drilled regions in the U.S. Drilling for oil in Texas began in 1866 at Oil Springs, in East Texas, followed by the first major oil discovery at the East Texas Corsicana Field. Following the first oil boom at the Spindletop Field in the upper Texas Gulf Coast Region, oil production in East and Central Texas continued to increase until its peak in the early 1950s at approximately 673 MMBbls.

Oil production in East and Central Texas has experienced a decline since the early 1950s, despite secondary waterflooding efforts in many of the fields (yielding a second production peak in the 1970's) and a handful of few tertiary recovery projects in some of the larger fields, Figure 5. Although the fields are mature and in decline, great opportunities exist for incremental oil recovery by applying CO_2-EOR technology. On average, oil recovery in the major East and Central Texas oil reservoirs has only been 35%, leaving a large amount of residual oil stranded in the ground. The close proximity of East and Central Texas to the Permian Basin CO_2 pipeline infrastructure and the refineries in the Gulf Coast Region makes this oil producing region ideal for CO_2-EOR applications.

Figure 5. East and Central Texas Oil Production Since 1950

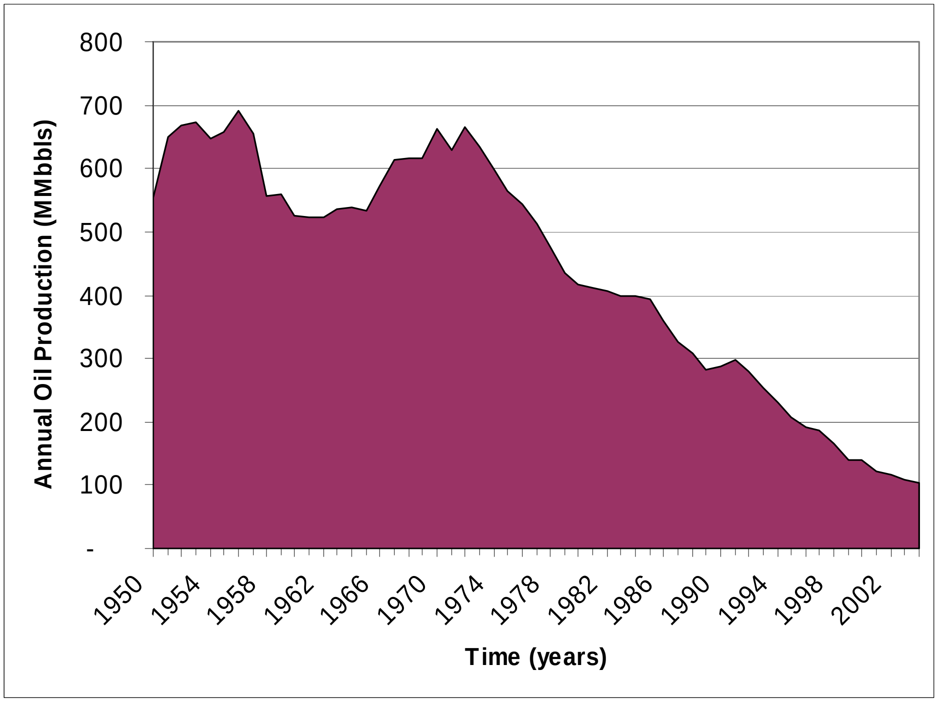


Table 8 presents the status and annual oil production for the ten largest East and Central Texas oil fields that account for just over one fifth of the oil production in this region. The table shows that four of the largest oil fields are in production decline. Arresting this decline oil production could be attained by applying enhanced oil recovery technology, particularly CO_2-EOR.

Table 8. Crude Oil Annual Production, Ten Largest East and Central Texas Oil Fields, 2001-2003 (Million Barrels per Year)

Major Oil Fields	2001	2002	2003	2004	Production Status
GIDDINGS (AUSTIN CHALK)	10.4	9.0	8.5	8.4	Declining
EAST TEXAS (ALL)	6.7	5.7	5.1	4.8	Declining
SPRABERRY (TREND AREA)*	5.6	5.4	5.6	6.3	Increasing
HAWKINS (ALL)*	3.6	3.6	3.2	2.7	**Declining**
PANHANDLE (HUTCHINSON)	0.9	0.8	0.7	0.6	Declining

HASTINGS, WEST (WEST)	0.8	0.6	0.6	0.6	Stable
CONROE (MAIN)	0.7	0.7	0.7	0.7	Stable
THOMPSON (ALL)	0.6	0.6	0.6	0.7	Stable
TOM O'CONNOR (5400)	0.4	0.3	0.4	0.5	Stable
WEBSTER (FRIO)	0.4	0.5	0.6	0.4	Stable

** Fields under EOR operations*

3.2 EXPERIENCE WITH IMPROVED OIL RECOVERY. Texas oil producers are familiar with using technology for improving oil recovery. For example, operators can draw upon the experiences of a number of CO_2-EOR floods in the Permian basin as well as the secondary (waterfloding) efforts in Texas. In addition, a large N_2-Immiscible flood has been conducted in the Hawkins field since 1987 that has allowed an additional 40 MMBbls of oil to be recovered.

3.3 THE "STRANDED OIL" PRIZE. Even though East and Central Texas oil production is declining, this does not mean that the resource base is depleted. The East and Central Texas reservoirs analyzed in this study still contain 66% of their OOIP (44.7 BBbls) after primary and secondary oil recovery. This large volume of remaining oil in-place (ROIP) is the "prize" for CO_2-EOR.

Table 9 provides information on the maturity and oil production history of 10 large East and Central Texas oil fields, each with primary/secondary estimated ultimate recovery of 400 million barrels or more.

Table 9. Selected Major Oil Fields of the East and Central Texas

	Field	Year Discovered	Cumulative Production (MBbl)	Estimated Reserves (MBbl)	Remaining Oil In-Place (MMBbl)
1	EAST TEXAS	1930	5,317,430	40,050	6,548
2	HAWKINS	1940	830,520	14,726	1,021
3	CONROE	1931	727,618	4,950	864
4	HASTINGS, WEST	1958	637,124	4,448	525

5	WEBSTER	1936	595,134	3,710	561
6	GIDDINGS	1960	429,580	61,990	601
7	SPRABERRY	1946	425,585	69,483	3,701
8	PANHANDLE	1921	383,939	5,964	1,565
9	THOMPSON	1921	372,946	4,260	461
10	TOM O'CONNOR	1934	339,920	111	793

** Fields with active CO_2 flooding*

3.4 REVIEW OF PRIOR STUDIES. A study was conducted in 1991 by the Texas Bureau of Economic Geology on the potential for CO_2-EOR in Texas — "Reduction of Greenhouse Gas Emissions through Underground CO_2 Sequestration in Texas Oil and Gas Reservoirs".

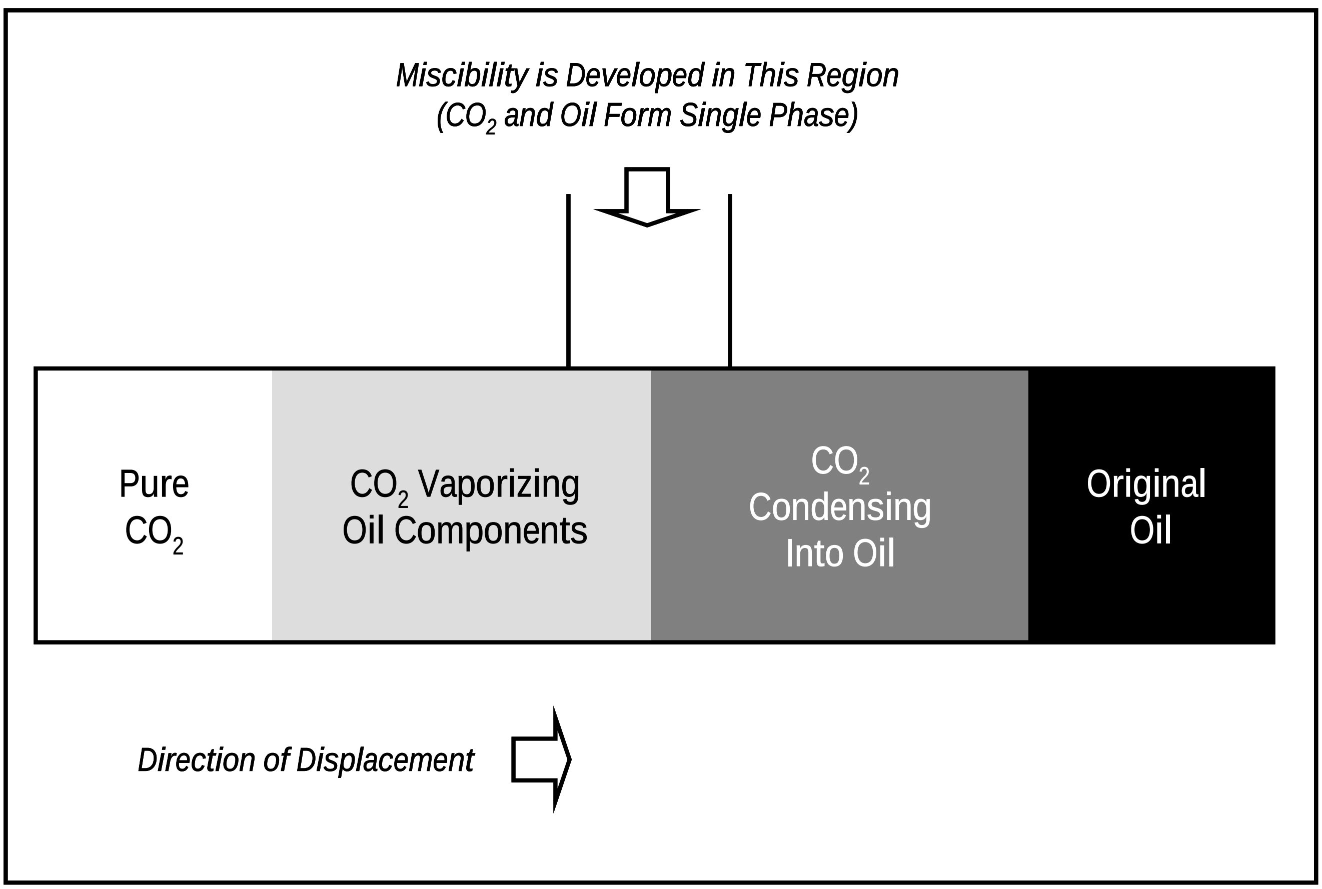
The study used a data base of 3,000 Texas oil reservoirs (all RR Districts) containing 197 billion barrels (BBbls) of OOIP. Of this, 57 billion barrels is noted as having been produced or proved. Of the remaining oil, 66 billion barrels is judged to be mobile oil and 74 billion barrels as residual (immobile) oil. Of the 3,000 oil reservoirs in the data base, 1,730 reservoirs were screened as being favorable for CO_2-EOR. These reservoirs were estimated to hold 80 BBbls of OOIP, and 31 BBbls of immobile residual oil. The selected fields are located within 90 miles of CO_2 producing power plants. The study estimated that an additional 8 BBbls could be recovered using CO_2-EOR, assuming a recovery factor of 10% of OOIP. A significant, though unstated, portion of the additional oil recovery is expected from fields located on the Gulf Coast near the state's large power plants.

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 6. One-Dimensional Schematic Showing the CO_2 Miscible Process.



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 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 7A. Carbon Dioxide, CH_4 and N_2 densities at 105^0F. At high pressures, CO_2 has a density close to that of a liquid and much greater than that of either methane or nitrogen. Densities were calculated with an equation of state (EOS).

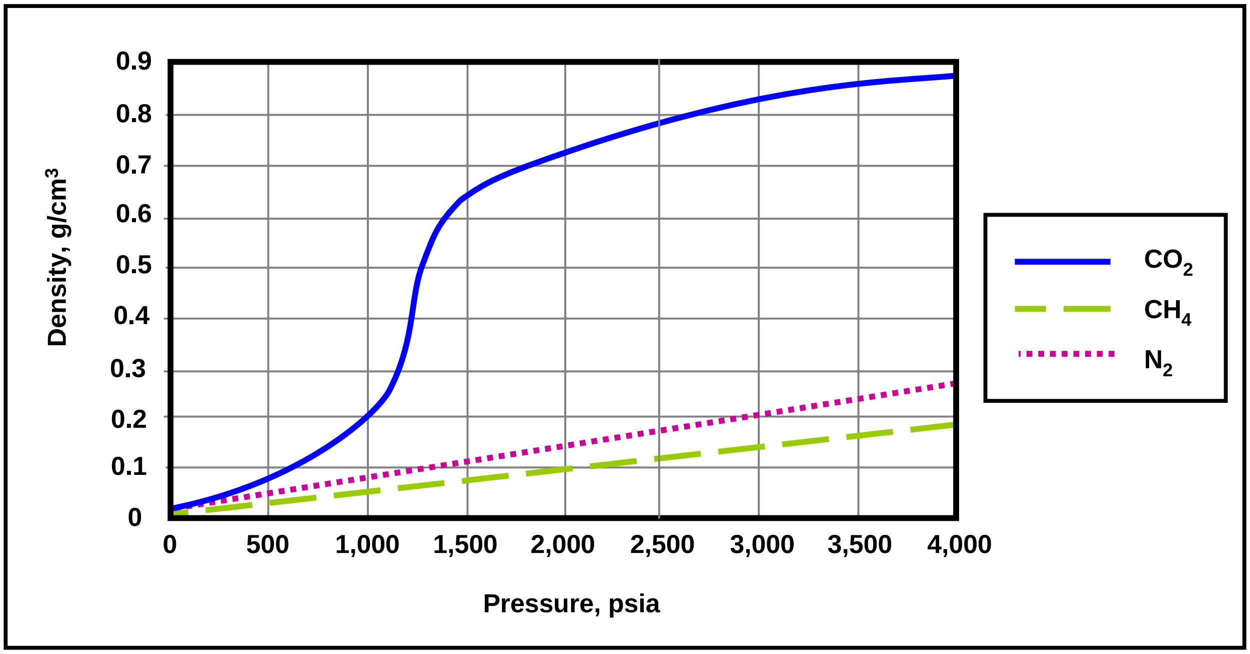


Figure 7B. Carbon Dioxide, CH_4 and N_2 viscosities at 105^0F. At high pressures, the viscosity of CO_2 is also greater then that of methane or nitrogen, although it remains low in comparison to that of liquids. Viscosities were calculated with an EOS.

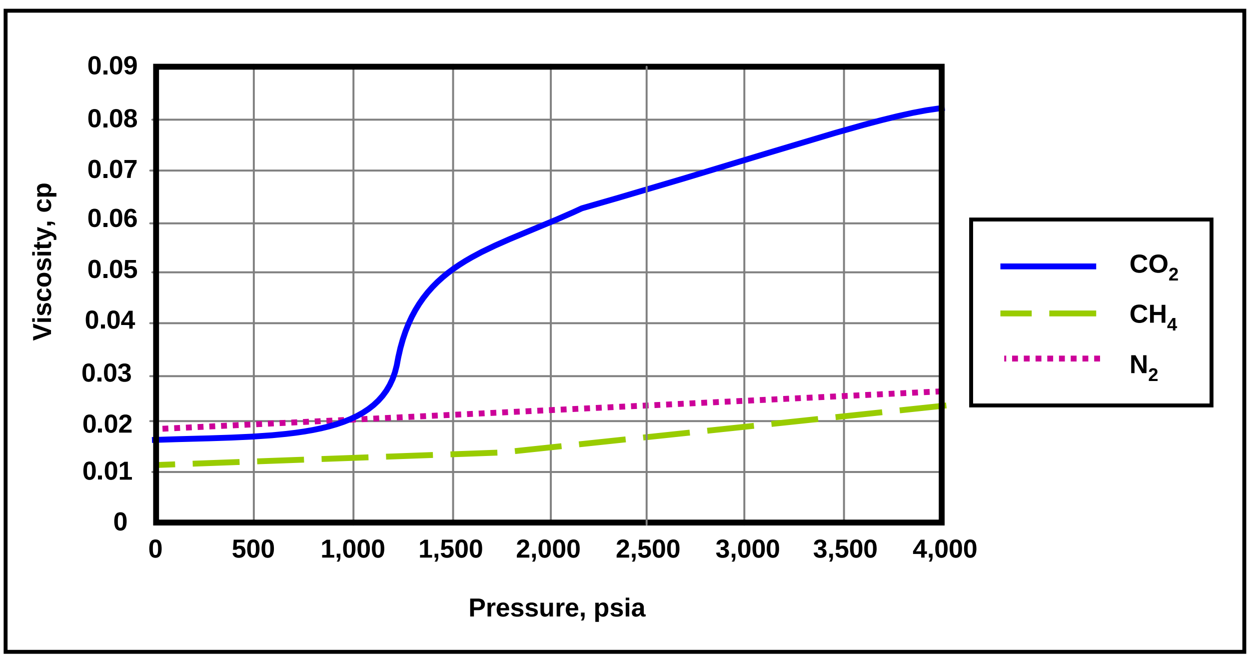


Figure 8A. Relative Oil Volume vs. Pressure for a Light West Texas Reservoir Fluid (Holm and Josendal).

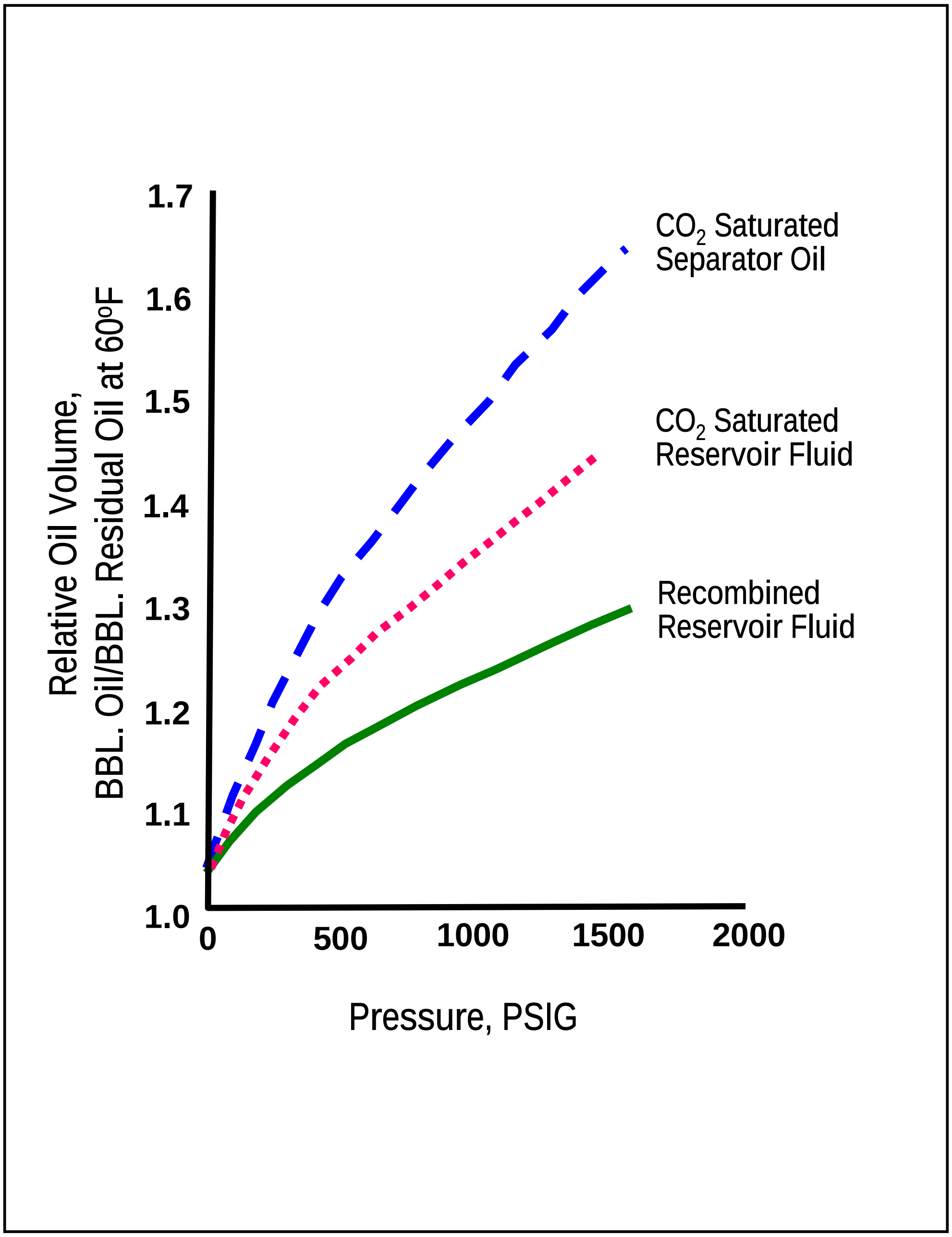


Figure 8B. Oil Swelling Factor vs. Pressure for a Heavy Oil in Turkey (Issever and Topkoya).

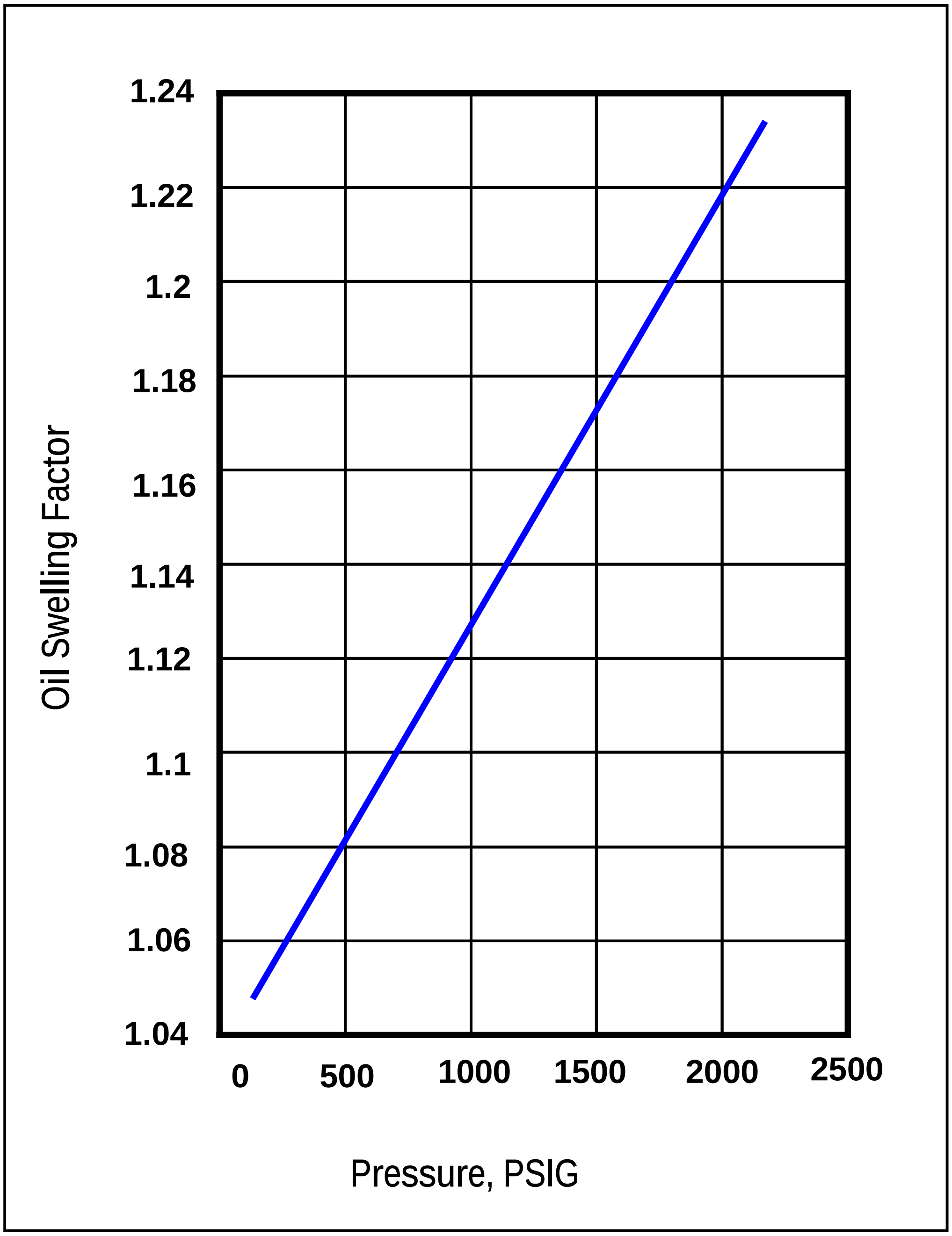
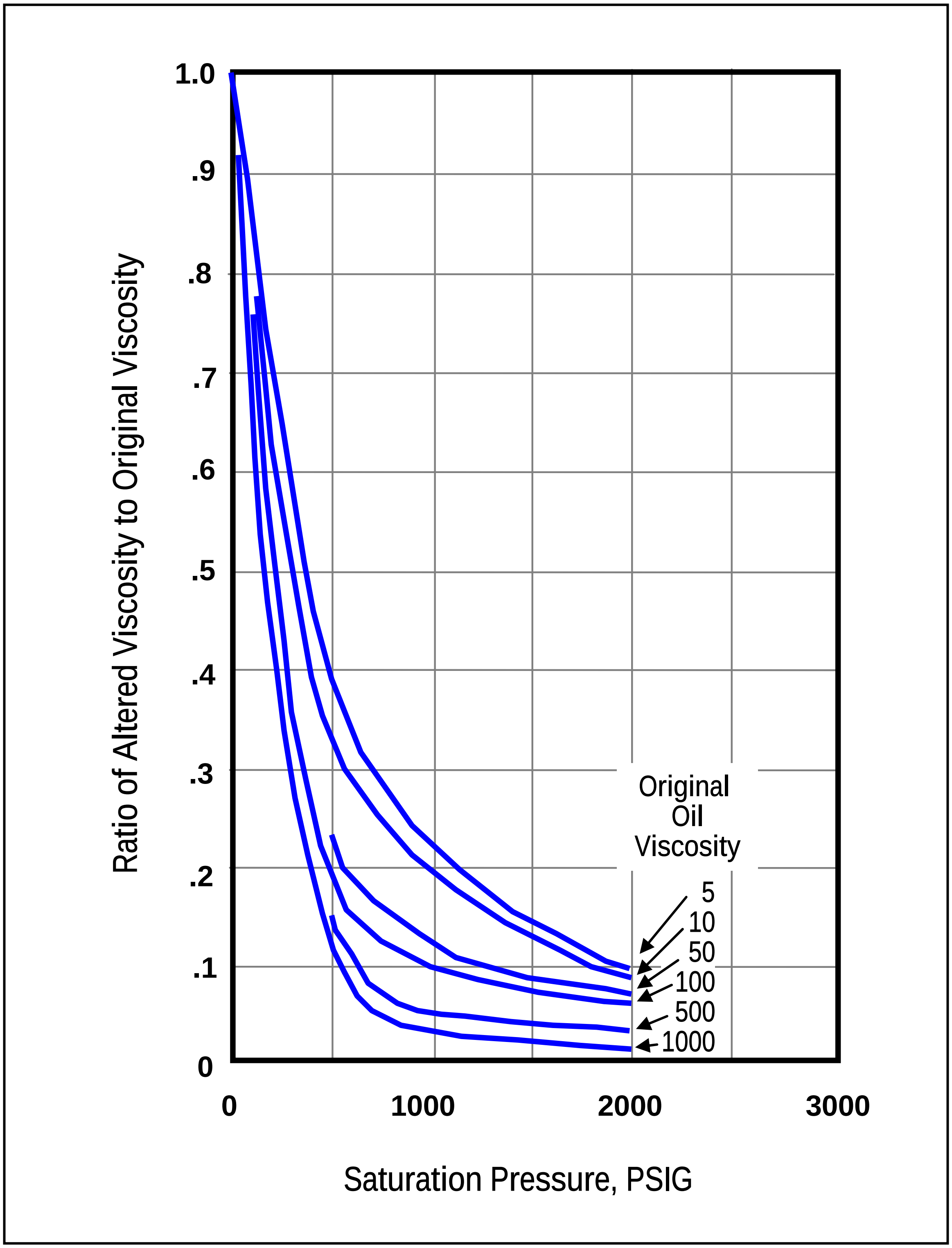


Figure 9. Viscosity Reduction Versus Saturation Pressure. (Simon and Graue).



5. STUDY METHODOLOGY

5.1 OVERVIEW. A seven part methodology was used to assess the CO_2-EOR potential of the East and Central Texas' oil reservoirs. The seven steps were: (1) assembling the 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; (6) constructing an economics model; and, (7) performing scenario 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 East and Central Texas Oil Reservoirs Data Base (all onshore districts excluding 8 and 8A, which are included in another study).

Table 10 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 East and Central Texas Major Oil Reservoirs Data Base contains 199 reservoirs, accounting for 65% of the oil expected to be ultimately produced in East and Central Texas by primary and secondary oil recovery processes.

Table 10. Reservoir Data Format: Major Oil Reservoirs Data Base

Basin Name	
Field Name	
Reservoir	

Reservoir Parameters:

	TORIS	ARI
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		

Oil Production

	TORIS	ARI
Producing Wells (active)		
Producing Wells (shut-in)		
2003 Production (Mbbl)		
Daily Prod - Field (Bbl/d)		
Cum Oil Production (MMbbl)		
EOY 2003 Oil Reserves (MMbbl)		
Water Cut		

Water Production

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

Injection

	TORIS	ARI
Injection Wells (active)		
Injection Wells (shut-in)		
2003 Water Injection (MMbbl)		
Daily Injection - Field (Mbbl/d)		
Cum Injection (MMbbl)		
Daily Inj per Well (Bbl/d)		

EOR

Type	
2003 EOR Production (MMbbls)	
Cum EOR Production (MMbbls)	
Reserves (MMbbls)	
Ultimate Recovery (MMbbls)	

Volumes

	TORIS	ARI
OOIP (MMbl)		
Cum P/S Oil (MMbl)		
2003 P/S Reserves (MMbl)		
Ult P/S Recovery (MMbl)		
Remaining (MMbbl)		
Ultimate Recovered (%)		

OOIP Volume Check

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

SROIP Volume Check

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

ROIP Volume Check

	TORIS	ARI
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 East and Central Texas; (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 deeper oil reservoirs that had sufficiently high oil gravity. A minimum reservoir depth of 3,000 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 17.5 ^{o}API was used to ensure the reservoir's oil had sufficient mobility, without requiring thermal injection. Table 11 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 11. East and Central Texas Oil Reservoirs Screened Amenable to CO_2-EOR

District	Field	Formation
A. Texas Gulf Coast		
TX 2	BLOOMINGTON	4600
TX 2	BONNIE VIEW	BONNIE VIEW
TX 2	GANADO, WEST	4700 ZONE
TX 2	GRETA	4400
TX 2	HELEN GOHLKE	WILCOX
TX 2	HEYSER	5400 NO 2
TX 2	HEYSER	5400 NO 3
TX 2	LA WARD, NORTH	FRIO
TX 2	LAKE PASTURE	H440 SAND
TX 2	MAURBRO	MARGINULINA
TX 2	MCFADDIN	4400
TX 2	PETTUS	PETTUS
TX 2	PLACEDO	PLACEDO
TX 2	REFUGIO-FOX	MAIN
TX 2	SLICK	WILCOX
TX 2	TOM O'CONNOR	4500 GRETA MASS.
TX 2	TOM O'CONNOR	5400 SAND
TX 2	TOM O'CONNOR	5500
TX 2	TOM O'CONNOR	5800
TX 2	TOM O'CONNOR	5900
TX 2	TOM O'CONNOR	CATAHOULA-FRIO-MIOCENE
TX 2	WEST RANCH	41A
TX 2	WEST RANCH	98A
TX 2	WEST RANCH	GLASSCOCK
TX 2	WEST RANCH	GRETA SAND
TX 2	WEST RANCH	TONEY
TX 2	WEST RANCH	WARD
TX 3	AMELIA	FRIO
TX 3	ANAHUAC	13A-2 FRIO FB
TX 3	BARBERS HILL	MIOCENE-FRIO
TX 3	CLEAR LAKE	FRIO
TX 3	CONROE	CONROE MAIN
TX 3	MAGNET WITHERS	All
TX 3	BRYAN	WOODBINE
TX 3	HUMBLE	All
TX 3	MANVEL	All others
TX 3	ORANGE	All
TX 3	MANVEL (OLIGOCENE)	OLIGOCENE
TX 3	SOUR LAKE	All
TX 3	WEST COLUMBIA	WEST
TX 3	WITHERS, NORTH	NORTH

Table 11. East and Central Texas Oil Reservoirs Screened Amenable to CO_2-EOR

District	Field	Formation
TX 3	WEST COLUMBIA NEW	NEW
TX 3	GILLOCK	EAST SEGMENT & BIG GAS
TX 3	GILLOCK, SOUTH	BIG GAS
TX 3	GOOSE CREEK	MIOCENE
TX 3	HANKAMER	MIOCENE SAND
TX 3	HASTINGS, EAST	EAST
TX 3	HASTINGS, WEST	WEST
TX 3	HULL MERCHANT	YEGUA
TX 3	LOVELLS LAKE	FRIO 2
TX 3	MARKHAM, NORTH-BAY CITY	WEST CORNELIUS
TX 3	MARKHAM, NORTH-BAY CITY	CARLSON
TX 3	OLD OCEAN	ARMSTRONG
TX 3	OYSTER BAYOU	SEABREEZE
TX 3	PIERCE JUNCTION	All
TX 3	RACCOON BEND	All
TX 3	RACCOON BEND	COCKFIELD
TX 3	SPINDLETOP	All
TX 3	THOMPSON	All others
TX 3	THOMPSON, NORTH	NORTH
TX 3	THOMPSON, SOUTH	FRIO POOL
TX 3	TOMBALL	COCKFIELD
TX 3	TOMBALL	SCHULTZ, SOUTHEAST
TX 3	WEBSTER	FRIO
TX 3	CHOCOLATE BAYOU	ALIBEL
TX 3	CHOCOLATE BAYOU	UPPER FRIO
TX 3	FAIRBANKS	FAIRBANKS
TX 3	FIG RIDGE	SEABREEZE
TX 3	GIDDINGS	AUSTIN CHALK
TX 3	HARDIN	FRAZIER
TX 3	KURTEN	WOODBINE
TX 3	LOVELLS LAKE	FRIO 1
TX 3	MERCHANT	EY 1B
TX 3	SILSBEE	YEGUA
TX 3	TRINITY BAY	FRIO 12
TX 3	HOUSTON, SOUTH	SOUTH
TX 3	SUGARLAND	FRIO
TX 3	THOMPSON, SOUTH	4400 SAND MIOCENE Y
TX 3	LIVINGSTON	WILCOX
TX 3	LIVINGSTON	YEGUA
TX 3	OLD OCEAN	CHENAULT
TX 3	SEGNO	ALL OTHERS
TX 3	SEGNO	WILCOX

Table 11. East and Central Texas Oil Reservoirs Screened Amenable to CO_2-EOR

District	Field	Formation
TX 3	SARATOGA WEST	UNNAMED
TX 4	ALAZAN NORTH	FRIO (ALL)
TX 4	BENAVIDES	ALL
TX 4	BORREGOS	ZONE R-13
TX 4	MIDWAY	MAIN MIDWAY SAND
TX 4	PLYMOUTH	HEEP
TX 4	PLYMOUTH	MAIN GRETA SAND
TX 4	PORTILLA	7400 SAND
TX 4	RINCON	FRIO SAND
TX 4	SEELIGSON UNIT	14 ZONE ALL
TX 4	SEELIGSON UNIT	19B ZONE ALL
TX 4	SEELIGSON UNIT	19C ZONE ALL
TX 4	SEJITA	HOCKLEY-JACKSON
TX 4	STRATTON	BERTRAM & WARDNER
TX 4	STRATTON	FRIO-VICKSBURG
TX 4	STRATTON	L-4
TX 4	TAFT	4400 SAND
TX 4	WHITE POINT EAST	FRIO
TX 4	WILLAMAR, WEST	WILLAMAR
TX 4	WILLAMAR	WILLAMAR
B. East Texas		
TX 5	BUFFALO	BUFFALO
TX 5	MEXIA	WOODBINE
TX 5	POWELL	MAIN
TX 5	SULPHUR BLUFF	PALUXY
TX 6	CAYUGA	ALL
TX 6	COKE	PALUXY
TX 6	EAST TEXAS	ALL
TX 6	FAIRWAY	JAMES LIME
TX 6	HAWKINS	ALL
TX 6	LONG LAKE	WOODBINE
TX 6	NECHES	WOODBINE
TX 6	PEWITT RANCH	PALUXY
TX 6	QUITMAN	ALL
TX 6	SAND FLAT	ALL
TX 6	SHAMBURGER LAKE	PALUXY
TX 6	TALCO	PALUXY
C. Central Texas		
TX 1	AWP	OLMOS
TX 1	BIG WELLS	EAST SAN MIGUEL LOWER
TX 1	BIG WELLS	SAN MIGUEL
TX 1	BIG FOOT	OLMOS B SAND W FU

Table 11. East and Central Texas Oil Reservoirs Screened Amenable to CO_2-EOR

District	Field	Formation
TX 1	CHARLOTTE	NAVARRO
TX 1	PEACH CREEK	AUSTIN CHALK
TX 1	PEARSALL	NAVARRO SAND
TX 7B	BOYD CONGLOMERATE	BEND CONGLOMERATE
TX 7B	CLAYTONVILLE	CANYON LIME
TX 7B	FLOWERS	CANYON SAND
TX 7B	HAMLIN EAST	ALL
TX 7B	KATZ	4800
TX 7B	KATZ	5100
TX 7B	NENA LUCIA	STRAWN BEEF
TX 7B	ROUND TOP	PALO-PINTO REEF
TX 7B	STEPHENS COUNTY REGULAR	ALL
TX 7B	THROCKMORTON COUNTY REGULAR	ALL
TX 7C	BARNHART	ELLENBURGER
TX 7C	BENEDUM	SPRABERRY
TX 7C	BIG LAKE	SAN ANDRES
TX 7C	CALVIN	DEAN
TX 7C	FARMER	SAN ANDRES
TX 7C	FORT CHADBOURNE	ODOM LIME
TX 7C	IAB	MENIELLE
TX 7C	JAMESON	PENN REEF
TX 7C	JAMESON	STRAWN
TX 7C	PEGASUS	ELLENBURGER
TX 7C	PEGASUS	SPRABERRY
TX 7C	SPRABERRY	TREND AREA
TX 7C	TODD-DEEP	CRINOIDAL
TX 7C	TODD-DEEP	ELLENBURGER
TX 9	BIG MINERAL CREEK	BARNES SAND
TX 9	KMA	STRAWN
TX 9	SADLER	PENNSYLVANIAN
TX 9	SHERMAN	7500 SAND
TX 9	SHERMAN	STRAWN
TX 9	SIVELLS BEND	STRAWN
TX 9	WALNUT BEND	REGULAR
TX 10	FARNSWORTH	MORROW UPPER
TX 10	PANHANDLE	CARSON
TX 10	PANHANDLE	HUTCHINSON
TX 10	RHF	MORROW

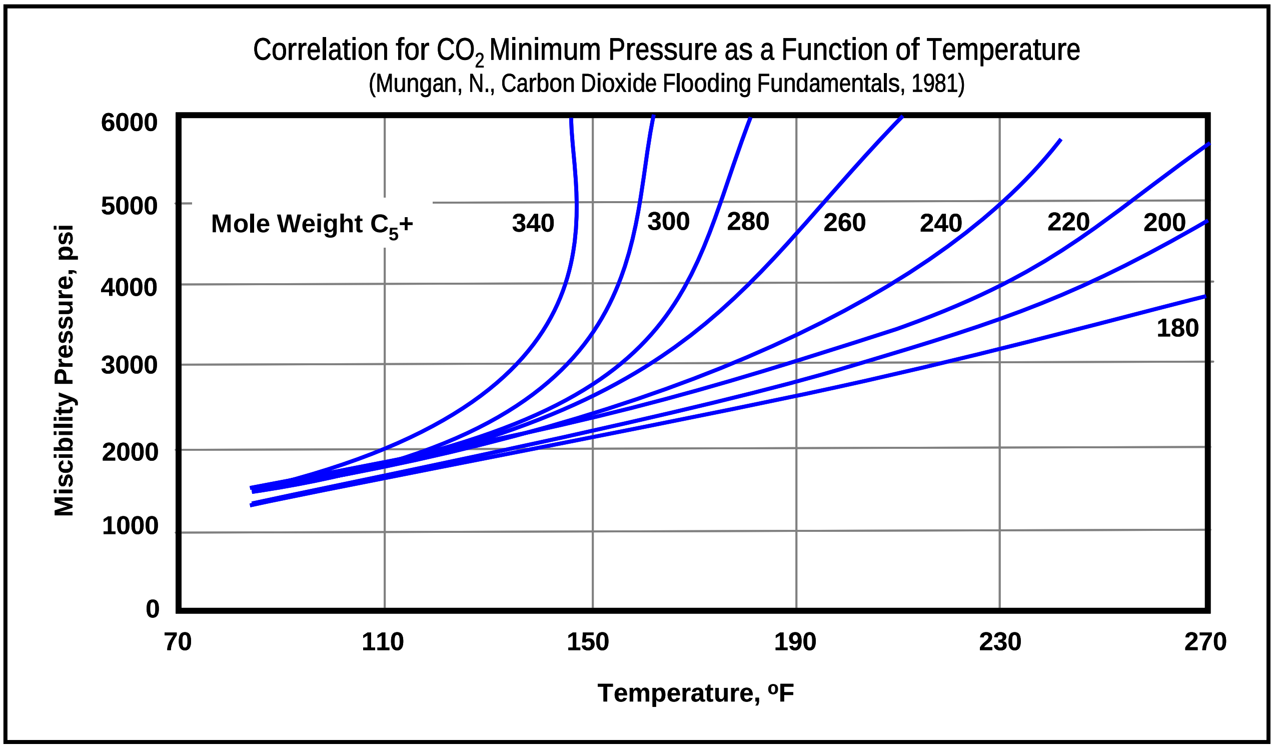
5.4 CALCULATING MINIMUM MISCIBILITY PRESSURE. The miscibility of a reservoir's oil with injected CO_2 is a function of pressure, temperature and the composition of the reservoir's oil. The study's approach to estimating whether a reservoir's oil will be miscible with CO_2, given fixed temperature and 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 Gulf Coast 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 °F, and MW C5+ is the molecular weight of pentanes and heavier fractions in the reservoir's oil.

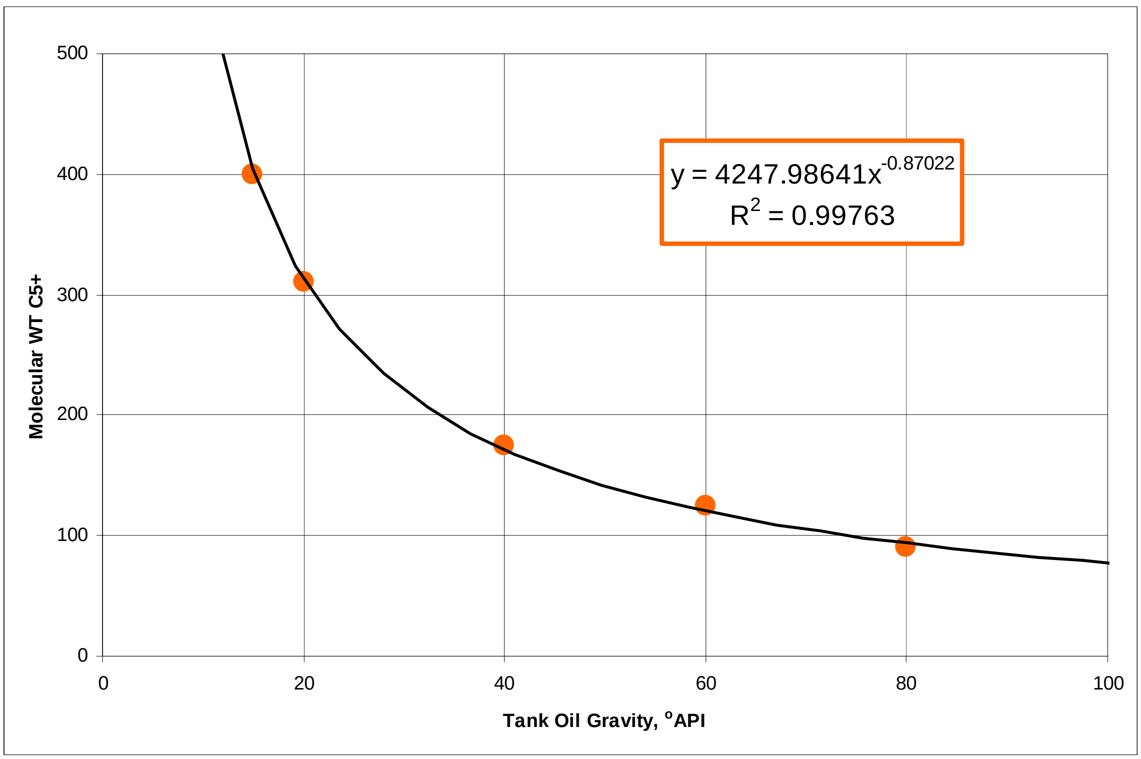
Figure 10.   Estimating CO_2 Minimum Miscibility Pressure.



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 11. Correlation of MW C5+ to Tank Oil Gravity



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. (Appendix B provides 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.

Table 12. Economic Model Established by the Study

Pattern-Level Cashflow Model		Advanced											
State				New Injectors	0.96								
Field				Existing Injectors	0.03			56					
Formation				Converted Producers	0.01								
Depth				New Producers	0.0								
Distance from Trunkline (mi)				Existing Producers	1.03								
# of Patterns				Disposal Wells	0.00								
Miscibility:	**Miscible**												
	Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
CO2 Injection (MMcf)			76	76	76	75	76	76	76	69	68	68	68
H2O Injection (Mbw)			19	19	19	19	19	19	19	23	23	23	23
Oil Production (Mbbl)			-	2	19	17	11	8	7	6	6	5	4
H2O Production (MBw)			48	47	29	22	21	21	21	21	23	23	24
CO2 Production (MMcf)			-	-	0	21	41	48	53	57	52	54	56
CO2 Purchased (MMcf)			76	76	75	55	34	28	22	12	16	14	12
CO2 Recycled (MMcf)			-	-	0	21	41	48	53	57	52	54	56
Oil Price ($/Bbl)	**$ 30.00**		$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00
Gravity Adjustment	**41**	Deg	$ 33.57	$ 33.57	$ 33.57	$ 33.57	$ 33.57	$ 33.57	$ 33.57	$ 33.57	$ 33.57	$ 33.57	$ 33.57
Gross Revenues ($M)			$ -	$ 57	$ 621	$ 584	$ 366	$ 272	$ 225	$ 195	$ 205	$ 158	$ 121
Royalty ($M)	**-12.5%**		$ -	$ (7)	$ (78)	$ (73)	$ (46)	$ (34)	$ (28)	$ (24)	$ (26)	$ (20)	$ (15)
Severance Taxes ($M)	**-2.3%**		$ -	$ (1)	$ (12)	$ (12)	$ (7)	$ (5)	$ (5)	$ (4)	$ (4)	$ (3)	$ (2)
Ad Valorum ($M)	**-2.1%**		$ -	$ (1)	$ (12)	$ (11)	$ (7)	$ (5)	$ (4)	$ (4)	$ (4)	$ (3)	$ (2)
Net Revenue($M)			$ -	$ 48	$ 519	$ 488	$ 306	$ 227	$ 188	$ 163	$ 171	$ 132	$ 101
Capital Costs ($M)													
New Well - D&C		$ (163)											
Reworks - Producers to Producers		$ (54)											
Reworks - Producers to Injectors		$ (0)											
Reworks - Injectors to Injectors		$ (2)											
Surface Equipment (new wells only)		$ (51)											
CO2 Recycling Plant		$ -	$ -	$ (111)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Water Injection Plant		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Trunkline Construction		$ (0)											
Total Capital Costs		$ (270)	$ -	$ (111)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cap Ex G&A	**0%**	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
CO2 Costs ($M)													
Total CO2 Cost ($M)			$ (113)	$ (113)	$ (113)	$ (88)	$ (64)	$ (56)	$ (50)	$ (35)	$ (40)	$ (37)	$ (34)
O&M Costs													
Operating & Maintenance ($M)			$ (41)	$ (41)	$ (41)	$ (41)	$ (41)	$ (41)	$ (41)	$ (41)	$ (41)	$ (41)	$ (41)
Lifting Costs ($/bbl)	**$ 0.25**		$ (12)	$ (12)	$ (12)	$ (10)	$ (8)	$ (7)	$ (7)	$ (7)	$ (7)	$ (7)	$ (7)
G&A	**20%**		(11)	(11)	(11)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)
Total O&M Costs			$ (64)	$ (64)	$ (64)	$ (61)	$ (59)	$ (58)	$ (58)	$ (58)	$ (58)	$ (58)	$ (58)
Net Cash Flow ($M)		$ (270)	$ (177)	$ (241)	$ 343	$ 339	$ 183	$ 113	$ 81	$ 70	$ 73	$ 37	$ 9
Cum. Cash Flow		$ (270)	$ (447)	$ (688)	$ (345)	$ (6)	$ 177	$ 290	$ 371	$ 441	$ 515	$ 552	$ 561
Discount Factor	**25%**	1.00	0.80	0.64	0.51	0.41	0.33	0.26	0.21	0.17	0.13	0.11	0.09
Disc. Net Cash Flow		$ (270)	$ (142)	$ (154)	$ 175	$ 139	$ 60	$ 30	$ 17	$ 12	$ 10	$ 4	$ 1
Disc. Cum Cash Flow		$ (270)	$ (412)	$ (566)	$ (391)	$ (252)	$ (192)	$ (162)	$ (145)	$ (133)	$ (123)	$ (119)	$ (119)
NPV (BTx)	25%	($114)											
NPV (BTx)	20%	$ (43)											
NPV (BTx)	15%	$ 55											
NPV (BTx)	10%	$ 194											
IRR (BTx)		17.61%											

Table 12. 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**
CO2 Injection (MMcf)		68	68	68	68	68	68	68	64	-	-	-	-	-	-
H2O Injection (Mbw)		23	23	23	23	23	23	23	25	57	44	-	-	-	-
Oil Production (Mbbl)		3	4	4	4	4	4	4	3	3	2	-	-	-	-
H2O Production (MBw)		23	23	23	23	23	23	23	23	34	40	-	-	-	-
CO2 Production (MMcf)		59	58	58	57	57	58	59	60	50	6	-	-	-	-
CO2 Purchased (MMcf)		9	10	10	11	11	10	9	4	-	-	-	-	-	-
CO2 Recycled (MMcf)		59	58	58	57	57	58	59	60	-	-	-	-	-	-
Oil Price ($/Bbl)	**$ 30.00**	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ -	$ -	$ -	$ -
Gravity Adjustment	**41**	$ 33.57	$ 33.57	$ 33.57	$ 33.57	$ 33.57	$ 33.57	$ 33.57	$ 33.57	$ 33.57	$ 33.57	$ 3.57	$ 3.57	$ 3.57	$ 3.57
Gross Revenues ($M)		$ 111	$ 117	$ 124	$ 138	$ 144	$ 138	$ 128	$ 114	$ 114	$ 74	$ -	$ -	$ -	$ -
Royalty ($M)	**-12.5%**	$ (14)	$ (15)	$ (16)	$ (17)	$ (18)	$ (17)	$ (16)	$ (14)	$ (14)	$ (9)	$ -	$ -	$ -	$ -
Severance Taxes ($M)	**-2.3%**	$ (2)	$ (2)	$ (2)	$ (3)	$ (3)	$ (3)	$ (3)	$ (2)	$ (2)	$ (1)	$ -	$ -	$ -	$ -
Ad Valorum ($M)	**-2.1%**	$ (2)	$ (2)	$ (2)	$ (3)	$ (3)	$ (3)	$ (2)	$ (2)	$ (2)	$ (1)	$ -	$ -	$ -	$ -
Net Revenue($M)		$ 93	$ 98	$ 104	$ 115	$ 121	$ 115	$ 107	$ 95	$ 95	$ 62	$ -	$ -	$ -	$ -
Capital Costs ($M)															
New Well - D&C															
Reworks - Producers to Producers															
Reworks - Producers to Injectors															
Reworks - Injectors to Injectors															
Surface Equipment (new wells only)															
CO2 Recycling Plant		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Water Injection Plant		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Trunkline Construction															
Total Capital Costs		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cap Ex G&A	**0%**	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
CO2 Costs ($M)															
Total CO2 Cost ($M)		$ (32)	$ (33)	$ (32)	$ (34)	$ (33)	$ (32)	$ (31)	$ (24)	$ -	$ -	$ -	$ -	$ -	$ -
O&M Costs															
Operating & Maintenance ($M)		$ (41)	$ (41)	$ (41)	$ (41)	$ (41)	$ (41)	$ (41)	$ (41)	$ (41)	$ (41)	$ -	$ -	$ -	$ -
Lifting Costs ($/bbl)	**$ 0.25**	$ (7)	$ (7)	$ (7)	$ (7)	$ (7)	$ (7)	$ (7)	$ (7)	$ (9)	$ (10)	$ -	$ -	$ -	$ -
G&A	**20%**	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	-	-	-	-
Total O&M Costs		$ (57)	$ (58)	$ (57)	$ (58)	$ (58)	$ (58)	$ (57)	$ (57)	$ (61)	$ (62)	$ -	$ -	$ -	$ -
Net Cash Flow ($M)		$ 4	$ 8	$ 14	$ 24	$ 30	$ 25	$ 18	$ 14	$ 35	$ (0)	$ -	$ -	$ -	$ -
Cum. Cash Flow		$ 564	$ 572	$ 587	$ 610	$ 640	$ 665	$ 683	$ 697	$ 732	$ 731	$ 731	$ 731	$ 731	$ 731
Discount Factor	**25%**	0.07	0.05	0.04	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00
Disc. Net Cash Flow		$ 0	$ 0	$ 1	$ 1	$ 1	$ 1	$ 0	$ 0	$ 0	$ (0)	$ -	$ -	$ -	$ -
Disc. Cum Cash Flow		$ (118)	$ (118)	$ (117)	$ (116)	$ (116)	$ (115)	$ (115)	$ (115)	$ (114)	$ (114)	$ (114)	$ (114)	$ (114)	$ (114)
NPV (BTx)	25%														
NPV (BTx)	20%														
NPV (BTx)	15%														
NPV (BTx)	10%														
IRR (BTx)															

Table 12. 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**	
CO_2 Injection (MMcf)		-	-	-	-	-	-	-	-	-	-	-	1,339
H_2O Injection (Mbw)		-	-	-	-	-	-	-	-	-	-	-	510
Oil Production (Mbbl)		-	-	-	-	-	-	-	-	-	-	-	119
H_2O Production (MBw)		-	-	-	-	-	-	-	-	-	-	-	556
CO_2 Production (MMcf)		-	-	-	-	-	-	-	-	-	-	-	901
CO_2 Purchased (MMcf)		-	-	-	-	-	-	-	-	-	-	-	494
CO_2 Recycled (MMcf)		-	-	-	-	-	-	-	-	-	-	-	846
Oil Price ($/Bbl)	**$ 30.00**	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
Gravity Adjustment	**41**	$ 3.57	$ 3.57	$ 3.57	$ 3.57	$ 3.57	$ 3.57	$ 3.57	$ 3.57	$ 3.57	$ 3.57	$ 3.57	
Gross Revenues ($M)		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 4,005
Royalty ($M)	**-12.5%**	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (501)
Severance Taxes ($M)	**-2.3%**	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (81)
Ad Valorum ($M)	**-2.1%**	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (75)
Net Revenue($M)		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 3,349
Capital Costs ($M)													
New Well - D&C													$ (163)
Reworks - Producers to Producers													$ (54)
Reworks - Producers to Injectors													$ (0)
Reworks - Injectors to Injectors													$ (2)
Surface Equipment (new wells only)													$ (51)
CO_2 Recycling Plant		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (111)
Water Injection Plant		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Trunkline Construction													$ (0)
Total Capital Costs		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (381)
Cap Ex G&A	**0%**	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
CO_2 Costs ($M)													
Total CO_2 Cost ($M)		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (994)
O&M Costs													
Operating & Maintenance ($M)		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (867)
Lifting Costs ($/bbl)	**$ 0.25**	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (169)
G&A	**20%**	-	-	-	-	-	-	-	-	-	-	-	$ (207)
Total O&M Costs		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (1,242)
Net Cash Flow ($M)		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 731
Cum. Cash Flow		$ 731	$ 731	$ 731	$ 731	$ 731	$ 731	$ 731	$ 731	$ 731	$ 731	$ 731	
Discount Factor	**25%**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Disc. Net Cash Flow		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (114)
Disc. Cum Cash Flow		$ (114)	$ (114)	$ (114)	$ (114)	$ (114)	$ (114)	$ (114)	$ (114)	$ (114)	$ (114)	$ (114)	
NPV (BTx)	25%												
NPV (BTx)	20%												
NPV (BTx)	15%												
NPV (BTx)	10%												
IRR (BTx)													

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 East and Central Texas oil basins and 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 $30 per barrel oil price was used to represent the moderate oil price case; a $40 per barrel oil price was used to represent the availability of federal/state risk sharing 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 5% of the oil price ($1.50 per Mcf at $30 per barrel) to represent the costs of a new transportation system bringing natural CO_2 to East and Central Texas’ oil basins. A lower CO_2 supply cost equal to 2% of the oil price ($0.80 per Mcf at $40 per barrel) 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 the past ten years in other areas, is successfully applied to the oil reservoirs of East and Central Texas. In addition, this scenario assumes that a comprehensive program of research, pilot tests and field demonstrations will help lower the risk inherent in applying new technology to these complex East and Central Texas oil reservoirs.
- The third scenario, entitled "Risk Mitigation," examines how the economic potential of CO_2-EOR could be increased through a strategy involving state production tax reductions, federal tax credits, royalty relief and/or higher world oil prices that together would add an equivalent $10 per barrel to the price that the producer uses for making capital investment decisions for CO_2-EOR.
- The final scenario, entitled "Ample Supplies of CO_2," low-cost, "EOR-ready" CO_2 supplies are aggregated from various industrial and natural sources. These include industrial high-concentration CO_2 emissions from hydrogen facilities, gas processing plants, chemical plants and other sources in the region. These would be augmented, in the longer-term, from concentrated CO_2 emissions from refineries and electric power plants. Capture of industrial CO_2 emissions could be part of a national effort for reducing greenhouse gas emissions.

6. RESULTS

***6.1 TEXAS GULF COAST*.** The Gulf Coast area of Texas (Railroad Districts #2, #3 and #4) produced approximately 42 million barrels of oil (114,600 barrels per day) in 2004.

Oil production in the Gulf Coast area of Texas began prior to 1900 and continued to rise until its peak in the early 1970s. Despite efforts to curb production decline through secondary recovery methods, oil production in the Texas Gulf Coast has continued to fall in recent years, Table 13. These waterfloods are now mature, with many of the fields near their production limits, calling for alternative methods for maintaining oil production.

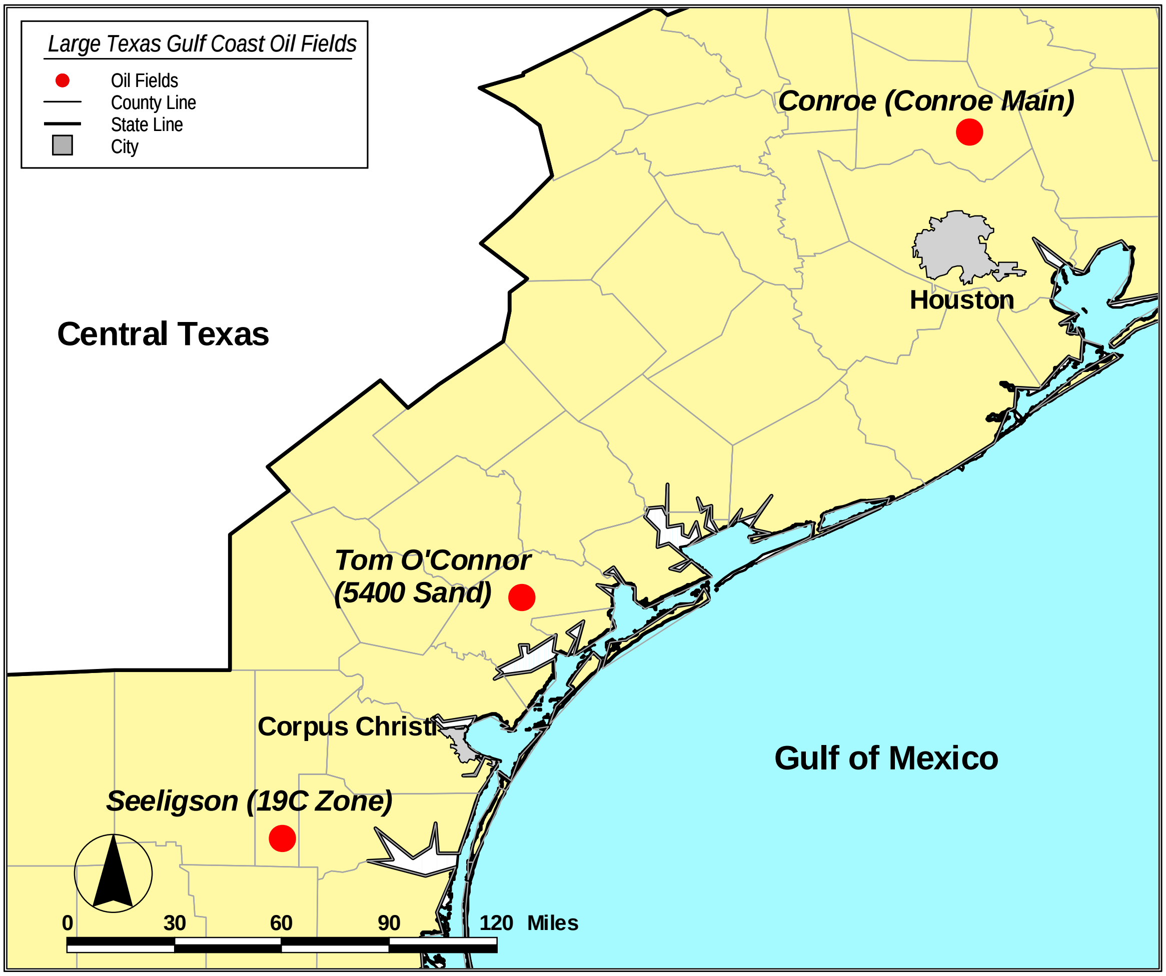
Table 13. Recent History of Texas Gulf Coast Oil Production

	Annual Oil Production	
	(MMBls/year)	(MBbls/day)
2000	50	135
2001	45	124
2002	44	119
2003	43	119
2004	42	115

Texas Gulf Coast Oil Fields. To better understand the potential of using CO_2-EOR in the light oil fields of the Texas Gulf Coast, this section examines, in more depth, three large oil fields, shown in Figure 12.

- Conroe (Conroe Main) - TX 3
- Tom O'Connor (5400 Sand) -TX 2
- Seeligson (19C Zone) – TX 4

Figure 12. Large Texas Gulf Coast Oil Fields



These three fields could serve as the "anchor" sites for CO_2-EOR projects distributed across the Texas Gulf Coast that could later be extended to other fields. The cumulative oil production, proved reserves and remaining oil in place (ROIP) for these three large light oil fields are set forth in Table 14.

Table 14. Status of Selected Large Oil
Texas Gulf Coast Oil Fields/Reservoirs (as of 2003)

	Large Fields/Reservoirs	Original Oil In-Place (MMBbls)	Cumulative Production (MMBbls)	Proved Reserves (MMBbls)	Remaining Oil In-Place (MMBbls)
1	Conroe (Conroe Main)	1,596	728	5	863
2	Tom O'Connor (5400 Sand)	1,133	340	1	792
3	Seeligson (19C Zone)	305	122	0	183

These three large "anchor" fields, each with 100 or more million barrels of ROIP, appear to be favorable for miscible CO_2 -EOR, based on their reservoir properties, Table 15.

Table 15. Reservoir Properties and Improved Oil Recovery Activity,
Selected Large Texas Gulf Coast Oil Fields/Reservoirs

	Large Fields/Reservoirs	Depth (ft)	Oil Gravity (°API)	Active Waterflood or Gas Injection
1	Conroe (Conroe Main)	5,000	38	Undergoing waterflooding
2	Tom O'Connor (5400 Sand)	5,450	31	Undergoing waterflooding
3	Seeligson (19C Zone)	5,750	43	Undergoing waterflooding

Past CO_2-EOR Projects.

<u>*Port Neches Field*</u>. A notable CO_2-EOR project, although no longer active, was completed in District 3 in Texaco's Port Neches Field, where CO_2-EOR was combined with horizontal drilling to increase oil production. Texaco and the DOE initiated a CO_2 injection project in the Marginulina Sand of the Port Neches field in 1993:

- The project planned to recover 19% OOIP or 2 MMBbl of by-passed oil, based on reservoir modeling, by the injection of an unstated HCPV of CO_2, at a peak CO_2 injection rate of 15 MMcf/d, with a WAG ratio of 0.05.
- Actual performance of the CO_2-EOR was reasonably in line with the forecast, at 14% of OOIP or 1.5 MMBbl.

In addition, two CO_2-EOR floods were conducted at Rose City South and Rose City North and one CO_2-EOR project was initiated in the Kurten field. While cited as successful by the operator, no public information could be found on these projects.

Future CO_2-EOR Potential. Texas Gulf Coast contains 103 reservoirs that are candidates for miscible and immiscible CO_2-EOR. Under “Traditional Practices” (and Base Case financial conditions, defined above), there are 15 economically attractive oil reservoir for miscible CO_2 flooding in Texas Gulf Coast. 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 Texas Gulf Coast increases to 58, providing 2.7 billion barrels of additional oil recovery, Table 16.

Table 16. Economic Oil Recovery Potential Under Two Technologic Conditions, Texas Gulf Coast

CO_2-EOR Technology	No. of Reservoirs Studied	Original Oil In-Place (MMBbls)	Technical Potential (MMBbls)	Economic Potential* (No. of Reservoirs)	Economic Potential* (MMBbls)
“Traditional Practices”	93	20,159	1,780	15	360
“State-of-the-art” Technology	103	21,499	4,100	58	2,680

** Oil price of $30 per barrel; CO_2 costs of $1.50/Mcf.*

Combining “State-of-the-art” technologies with risk mitigation incentives and/or higher oil prices and lower cost CO_2 supplies would enable CO_2-EOR in the Texas Gulf Coast to recover 3.8 billion barrels of CO_2-EOR oil, from 91 major reservoirs, Table 17.

Table 17. Economic Oil Recovery Potential with More Favorable Financial Conditions, Texas Gulf Coast

More Favorable Financial Conditions	Technical Potential (MMBbls)	Economic Potential (No. of Reservoirs)	Economic Potential (MMBbls)
Plus: Risk Mitigation Incentives*	4,100	70	3,140
Plus: Low Cost CO_2 Supplies**	4,100	91	3,750

** Oil price of $40 per barrel, adjusted for gravity and location differentials; CO_2 supply costs, $2.00/Mcf*

*** CO_2 supply costs, $0.80/Mcf*

6.2 EAST TEXAS. East Texas (Railroad Districts #5 and #6) produced approximately 20 million barrels of oil (55,200 barrels per day) in 2004.
Despite efforts to curb production decline through secondary recovery methods, oil production in East Texas has continued to fall in recent years, Table 18. These waterfloods are now mature, with many of the fields near their production limits, calling for alternative methods for maintaining oil production.

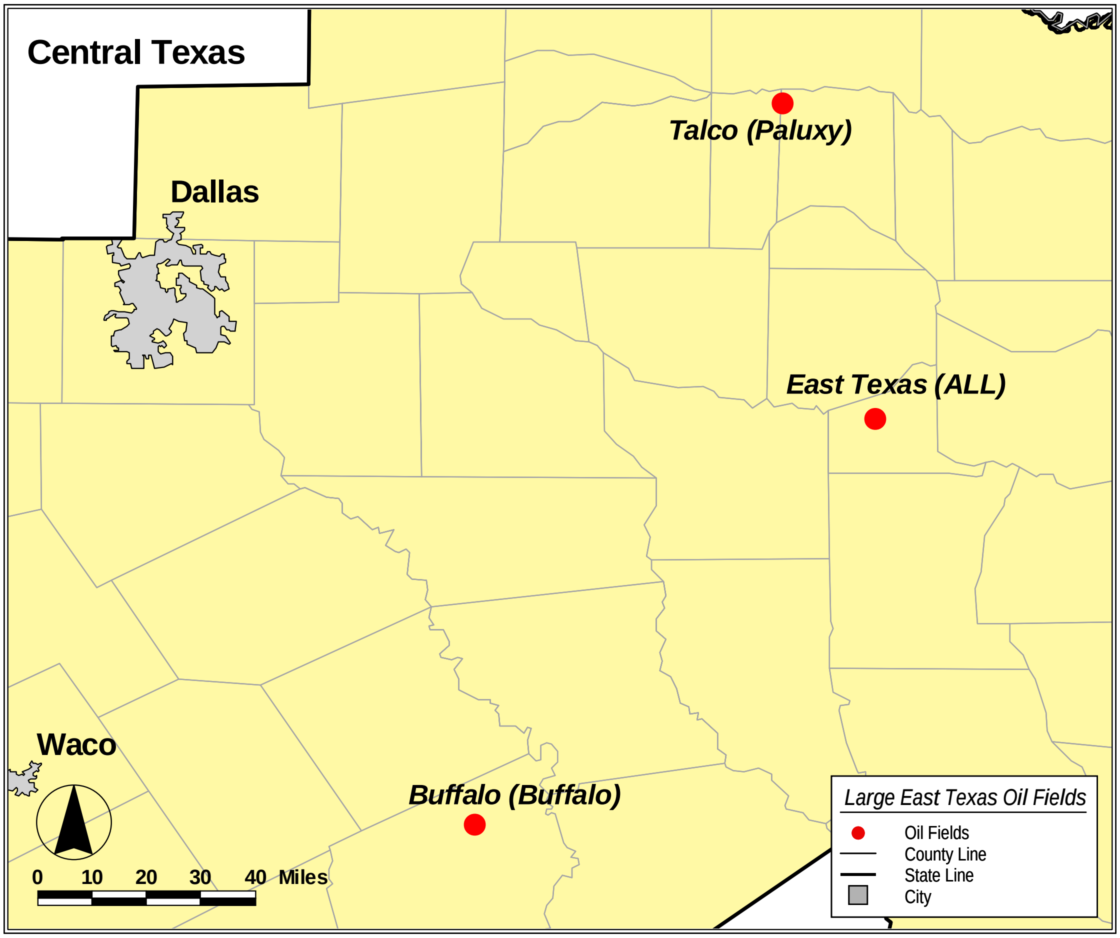
Table 18. Recent History of East Texas Oil Production

	Annual Oil Production	
	(MMBls/year)	(MBbls/day)
2000	29	80
2001	26	70
2002	23	63
2003	22	59
2004	20	55

East Texas Oil Fields. To better understand the potential of using CO_2-EOR in the light oil fields of East Texas, this section examines, in more depth, three large oil fields, shown in Figure 13.

- East Texas (All) -TX 6
- Buffalo (Buffalo) – TX 5
- Talco (Paluxy) – TX 6

Figure 13. Large East Texas Oil Fields



These three fields could serve as the "anchor" sites for CO_2-EOR projects distributed across East Texas that could later be extended to other fields. The cumulative oil production, proved reserves and remaining oil in place (ROIP) for these three large light oil fields are set forth in Table 19.

Table 19. Status of Selected Large East Texas Oil Fields/Reservoirs (as of 2003)

	Large Fields/Reservoirs	Original Oil In-Place (MMBbls)	Cumulative Production (MMBbls)	Proved Reserves (MMBbls)	Remaining Oil In-Place (MMBbls)
1	East Texas (All)	11,906	5,317	40	6,549
2	Buffalo (Buffalo)	598	4	0.2	594
3	Talco (Paluxy)	742	294	5	444

These three large "anchor" fields, each with 400 or more million barrels of ROIP, appear to be favorable for miscible CO_2 -EOR, based on their reservoir properties, Table 20.

Table 20. Reservoir Properties and Improved Oil Recovery Activity, Selected Large East Texas Oil Fields/Reservoirs

	Large Fields/Reservoirs	Depth (ft)	Oil Gravity (^oAPI)	Active Waterflood or Gas Injection
1	East Texas (All)	3,650	39	Undergoing waterflooding
2	Buffalo (Buffalo)	5,720	27	None
3	Talco (Paluxy)	4,290	22	Undergoing waterflooding

Past CO_2-EOR Projects. Three CO_2-EOR floods were conducted in East Texas in the Talco, Pittsburg and Slocum fields, however, no public information could be found on these projects.

Future CO_2-EOR Potential. East Texas contains 16 reservoirs that are candidates for miscible and immiscible CO_2-EOR. Under "Traditional Practices" (and Base Case financial conditions, defined above), 4 oil reservoirs are economically attractive for miscible CO_2 flooding in East Texas. 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 Texas increases to 12, providing 3.4 billion barrels of additional oil recovery, Table 21.

Table 21. Economic Oil Recovery Potential Under Two Technologic Conditions, East Texas

CO_2-EOR Technology	No. of Reservoirs Studied	Original Oil In-Place (MMBbls)	Technical Potential (MMBbls)	Economic Potential* (No. of Reservoirs)	Economic Potential* (MMBbls)
“Traditional Practices”	10	13,971	1,280	4	1,120
“State-of-the-art” Technology	16	18,464	3,500	12	3,350

** Oil price of $30 per barrel; CO_2 costs of $1.50/Mcf.*

Combining “State-of-the-art” technologies with risk mitigation incentives and/or higher oil prices and lower cost CO_2 supplies would enable CO_2-EOR in East Texas to recover 3.5 billion barrels of CO_2-EOR oil from 13 major reservoirs, Table 22.

Table 22. Economic Oil Recovery Potential with
More Favorable Financial Conditions, East Texas

More Favorable Financial Conditions	Technical Potential (MMBbls)	Economic Potential (No. of Reservoirs)	Economic Potential (MMBbls)
Plus: Risk Mitigation Incentives*	3,500	13	3,480
Plus: Low Cost CO_2 Supplies**	3,500	13	3,480

** Oil price of $40 per barrel, adjusted for gravity and location differentials; CO_2 supply costs, $2.00/Mcf*
*** CO_2 supply costs, $0.80/Mcf*

6.3 CENTRAL TEXAS. Central Texas (Railroad Districts #1, #7B, #7C, #9 and #10) produced approximately 53 million barrels of oil (146,400 barrels per day) in 2004. Despite efforts to curb production decline through secondary recovery methods, oil production in Central Texas has continued to fall in recent years, Table 23. These waterfloods are now mature, with many of the fields near their production limits, calling for alternative methods for maintaining oil production.

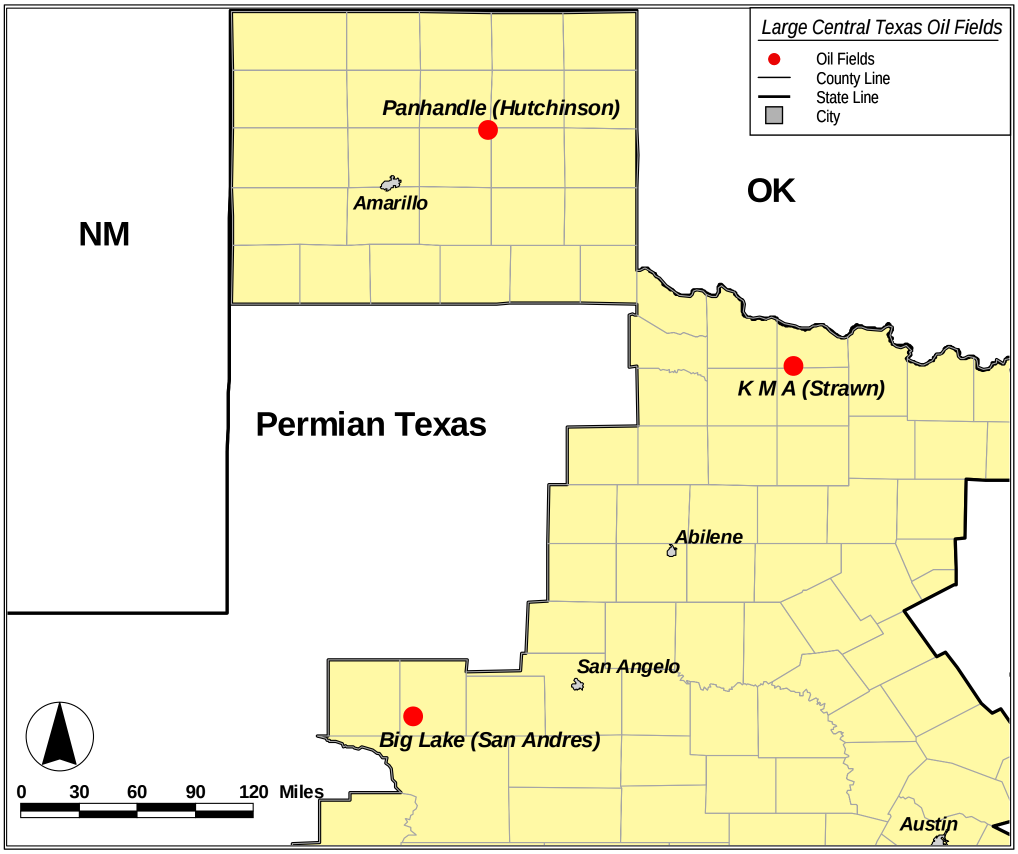
Table 23. Recent History of Central Texas Oil Production

	Annual Oil Production	
	(MMBls/year)	(MBbls/day)
2000	66	181
2001	62	169
2002	57	155
2003	55	152
2004	53	146

Texas Oil Fields. To better understand the potential of using CO_2-EOR in the light oil fields of Central Texas, this section examines, in more depth, three large oil fields, shown in Figure 14.

- Panhandle (Hutchinson) - TX 10
- KMA (Strawn) – TX 9
- Big Lake (San Andres) – TX 7C

Figure 14. Large Central Texas Oil Fields



These three fields could serve as the "anchor" sites for CO_2-EOR projects distributed across Central Texas that could later be extended to other fields. The cumulative oil production, proved reserves and remaining oil in place (ROIP) for these three large light oil fields are set forth in Table 24.

Table 24. Status of Selected Large Central Texas Oil Fields/Reservoirs (as of 2003)

	Large Fields/Reservoirs	Original Oil In-Place (MMBbls)	Cumulative Production (MMBbls)	Proved Reserves (MMBbls)	Remaining Oil In-Place (MMBbls)
1	Panhandle (Hutchinson)	1,955	384	6	1,565
2	KMA (Strawn)	593	181	5	407
3	Big Lake (San Andres)	305	135	3	168

These three large "anchor" fields, each with 100 or more million barrels of ROIP, appear to be favorable for miscible CO_2 -EOR, based on their reservoir properties, Table 25.

Table 25. Reservoir Properties and Improved Oil Recovery Activity, Selected Large Central Texas Oil Fields/Reservoirs

	Large Fields/Reservoirs	Depth (ft)	Oil Gravity (°API)	Active Waterflood or Gas Injection
1	Panhandle (Hutchinson)	3,000	41	Undergoing waterflooding
2	KMA (Strawn)	3,690	40	Undergoing waterflooding
3	Big Lake (San Andres)	3,000	40	Undergoing waterflooding

Past CO_2-EOR Projects.

<u>*Spraberry Trend Area*</u>. The only active CO_2-EOR project in Texas, outside of the Permian Basin, is occurring in the Spraberry Trend Area (District 7C), although limited in scope given the recent success of renewed waterflooding. CO_2 injection into the E.T. O'Daniel Pilot Area of the Spraberry Field began in February 2001, and initial results indicated that large volumes of CO_2 were being retained in the reservoir, as would be expected in order to push oil into production wells. However, as of early 2004, very little CO_2 was being injected into the Spraberry Trend Area, due to the success of waterflooding in the pilot area.

Future CO_2-EOR Potential. Central Texas contains 42 reservoirs that are candidates for miscible and immiscible CO_2-EOR. Under "Traditional Practices" (and Base Case financial conditions, defined above), there are 9 economically attractive oil reservoir for miscible CO_2 flooding in Central Texas. 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 Central Texas increases to 22, providing 1.3 billion barrels of additional oil recovery, Table 26.

Table 26. Economic Oil Recovery Potential Under Two Technologic Conditions, Central Texas

CO_2-EOR Technology	No. of Reservoirs Studied	Original Oil In-Place (MMBbls)	Technical Potential (MMBbls)	Economic Potential*	
				(No. of Reservoirs)	(MMBbls)
"Traditional Practices"	42	13,172	1,560	9	160
"State-of-the-art" Technology	42	13,172	3,368	22	1,260

** Oil price of $30 per barrel; CO_2 costs of $1.50/Mcf.*

Combining "State-of-the-art" technologies with risk mitigation incentives and/or higher oil prices and lower cost CO_2 supplies would enable CO_2-EOR in Central Texas to recover 1.3 billion barrels of CO_2-EOR oil (from 24 major reservoirs), Table 27.

Table 27. Economic Oil Recovery Potential with More Favorable Financial Conditions, Central Texas

More Favorable Financial Conditions	Technical Potential (MMBbls)	Economic Potential	
		(No. of Reservoirs)	(MMBbls)
Plus: Risk Mitigation Incentives*	3,368	22	1,260
Plus: Low Cost CO_2 Supplies**	3,368	24	1,330

** Oil price of $40 per barrel, adjusted for gravity and location differentials; CO_2 supply costs, $2.00/Mcf*

*** CO_2 supply costs, $0.80/Mcf*

Appendix A

Using *CO_2-PROPHET* for Estimating Oil Recovery

Model Development

The study utilized the *CO_2-PROPHET* model to calculate the incremental oil produced by CO_2-EOR from the large Texas 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 California 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.

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

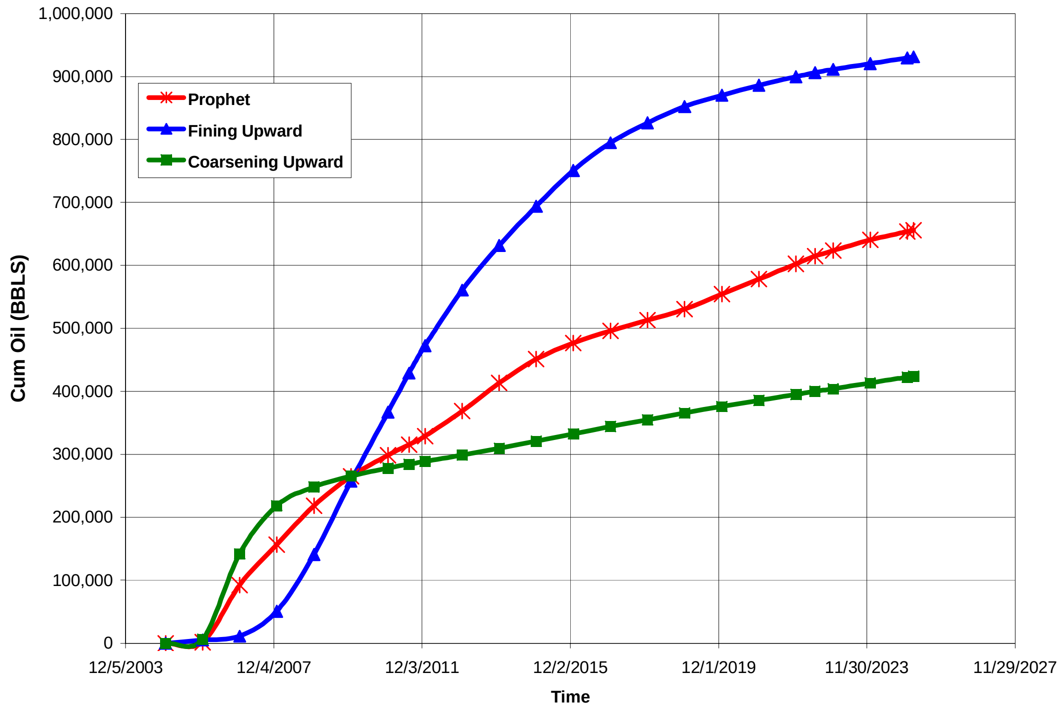
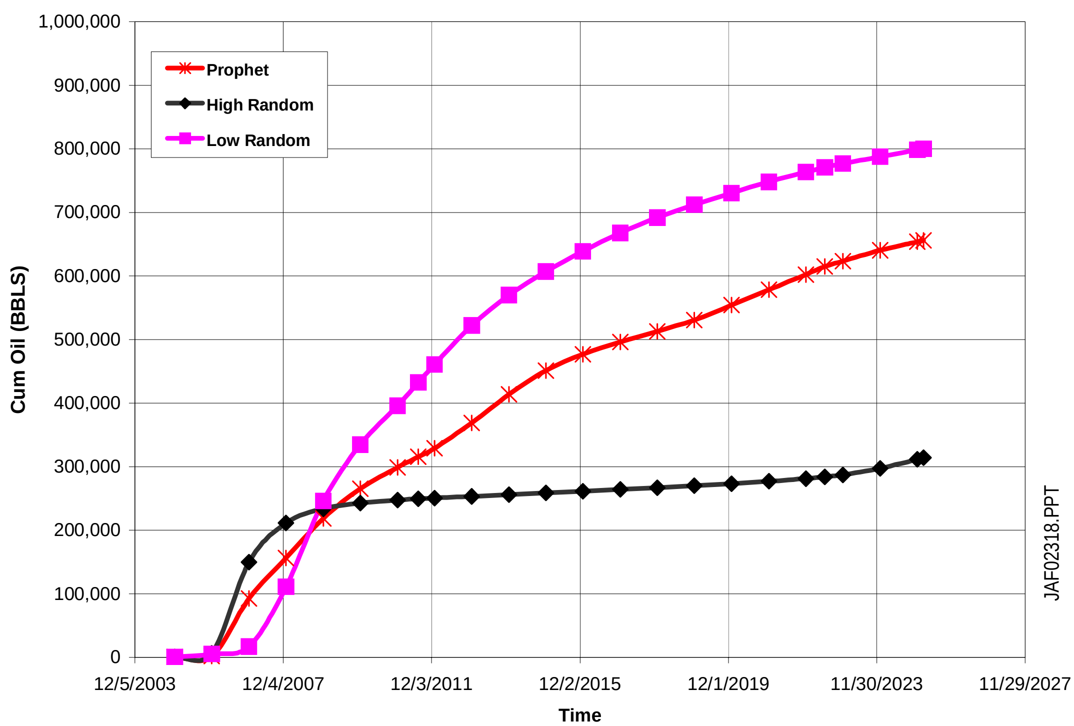


Figure A-2. CO_2-*PROPHET* and *GEM*: Comparison to Random Permeability Cases of *GEM*



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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*:

- *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

Texas CO_2-EOR Cost Model

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 2003 JAS cost study recently published by API for the Texas Railroad Districts (RRD's) 1-10.

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 following equations were derived for

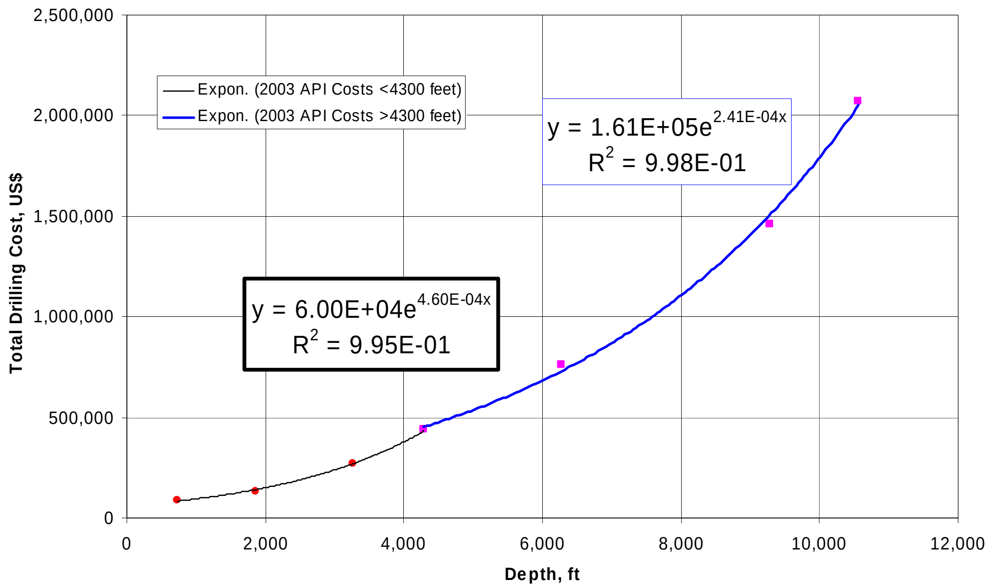
The total drilling equation is:

Costs = $a_0\ e^{a_1 D}$
Where D = depth

	RRD 1	RRD 2	RRD 3	RRD 4	RRD 5	RRD 6	RRD 7b	RRD 7c	RRD 9	RRD 10
Depth	<4,300'	ALL	ALL	<11,000	<11,000	<11,000	ALL	<8,400	<8,400	ALL
a_0	$6.0x10^4$	$1.0x10^4$	$9.4x10^4$	$1x10^5$	$1x10^5$	$1x10^5$	$2.5x10^4$	$2x10^5$	$3x10^4$	$5x10^4$
a_1	$4x10^{-4}$	$3x10^{-4}$	$3x10^{-4}$	$3x10^{-4}$	$3x10^{-4}$	$3x10^{-4}$	$5x10^{-4}$	$3x10^{-4}$	$4x10^{-4}$	$3x10^{-4}$
Depth	>4300'	-	-	>11,000	>11,000	>11,000	-	>8,400	>8,400	-
a_0	$1.6x10^5$	-	-	$4x10^3$	$4x10^3$	$4x10^3$	-	$7x10^4$	$4x10^3$	-
a_1	$2x10^{-4}$	-	-	$6x10^{-4}$	$6x10^{-4}$	$6x10^{-4}$	-	$3x10^{-4}$	$9x10^{-4}$	-

Figure B-1 provides the details for the cost equation and illustrates the "goodness of fit" for the well D&C cost equation for Texas RRD 1. Similar fits were made for the other RRD's

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



In order to bring the 2003 API drilling costs (the most recent available) into 2004 numbers where increased oil prices are expected to result in significantly increased drilling costs, a relationship was established between average drilling costs and average annual oil prices. Drillings costs from the ten year period of 1994-2003 (API data) were plotted versus the three year weighted average annual oil prices for those years (EIA Annual Energy Review, 2004) and the following relationship was established:

Drilling costs (per foot) = \$5.04(annual oil price) – \$3.2116.

Applying the 2004 average oil price of \$36.77 gives a drilling cost of \$182 per foot and an increase of 25.6% over the 2003 cost of \$145 per foot. Therefore, drilling and completion costs were increased by 25% over the West Texas D&C cost calculations to reflect this increase in 2004 drilling costs.

2. <u>Lease Equipment Costs for New Producing Wells.</u> The costs for equipping a new oil production well are based on data reported by the EIA in their 2004 "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 equations contain 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 equations are:

Texas RRD 3
Production Well Equipping Costs = $c_0 + c_1D$
Where: c_o = \$69,317 (fixed)

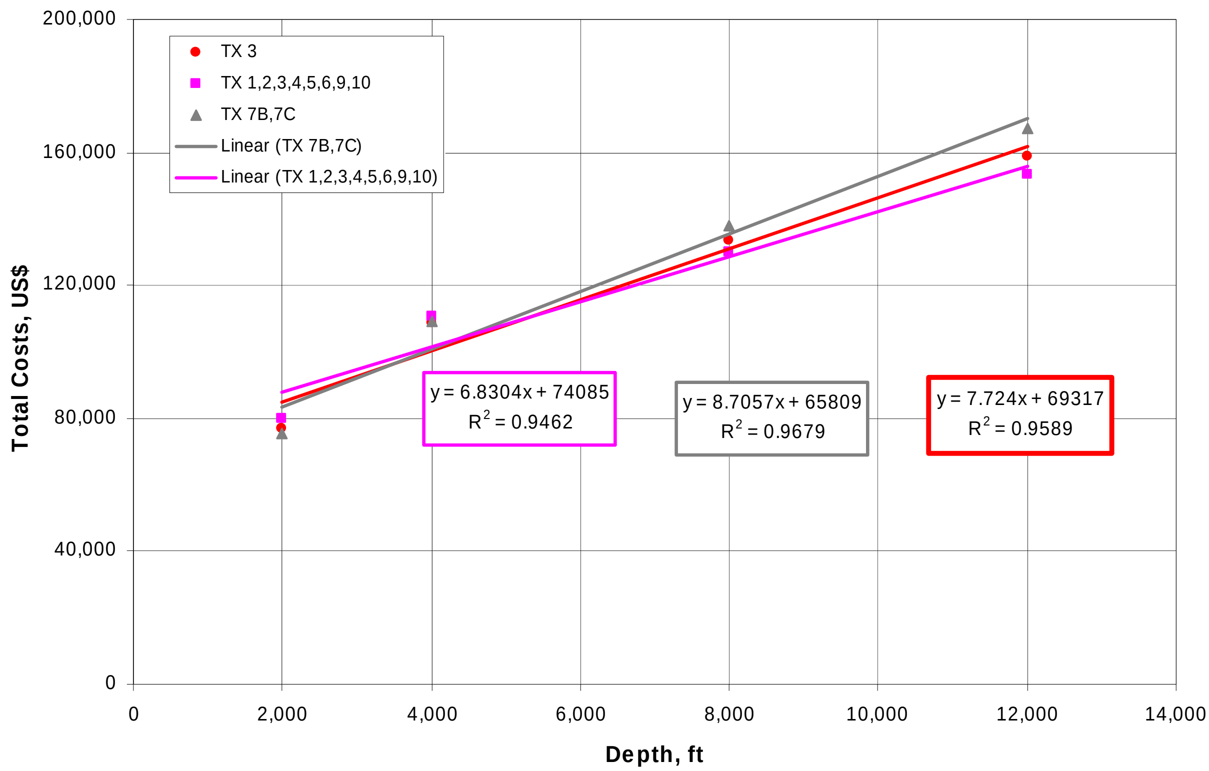
c_1 = \$7.72 per foot
D is well depth

Texas RRD 1,2.3,4,5,6,9,10
Production Well Equipping Costs = $c_0 + c_1D$
Where: c_o = \$74,085 (fixed)
c_1 = \$6.83 per foot
D is well depth

Texas RRD 7B,7C
Production Well Equipping Costs = $c_0 + c_1D$
Where: c_o = \$74,085 (fixed)
c_1 = \$6.83 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 Cost for a New Oil Production Well in West Texas vs. Depth



3. <u>Lease Equipment Costs for New Injection Wells.</u> The costs for equipping a new injection well in Texas 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 equations for the Texas Railroad Districts are:

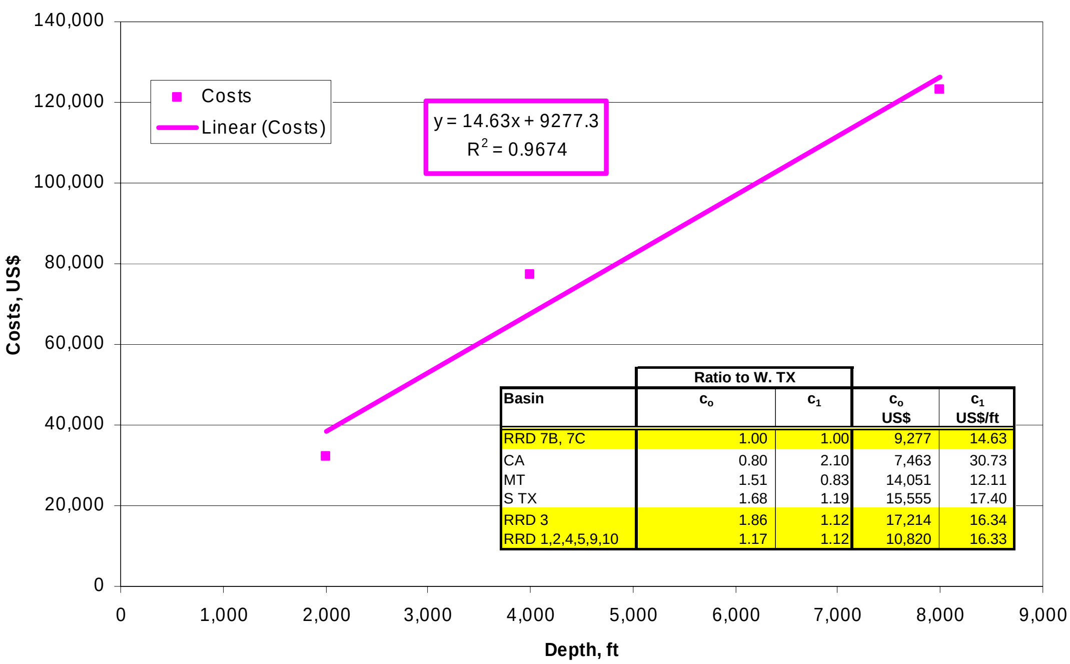
RRD 3 Injection Well Equipping Costs = $c_0 + c_1D$
Where: c_o = \$17,214 (fixed)
c_1 = \$16.34 per foot
D is well depth

RRD 1,2,4,5,9,10 Injection Well Equipping Costs = $c_0 + c_1D$
Where: c_o = \$10,820 (fixed)
c_1 = \$16.33 per foot
D is well depth

RRD 7B, 7C Injection Well Equipping Costs = $c_0 + c_1D$
Where: c_o = \$9,277 (fixed)
c_1 = \$14.63 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 remaining Texas cost equations.

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



Basin	Ratio to W. TX c_o	Ratio to W. TX c_1	c_o US\$	c_1 US\$/ft
RRD 7B, 7C	1.00	1.00	9,277	14.63
CA	0.80	2.10	7,463	30.73
MT	1.51	0.83	14,051	12.11
S TX	1.68	1.19	15,555	17.40
RRD 3	1.86	1.12	17,214	16.34
RRD 1,2,4,5,9,10	1.17	1.12	10,820	16.33

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 equations for the Railroad Districts are:

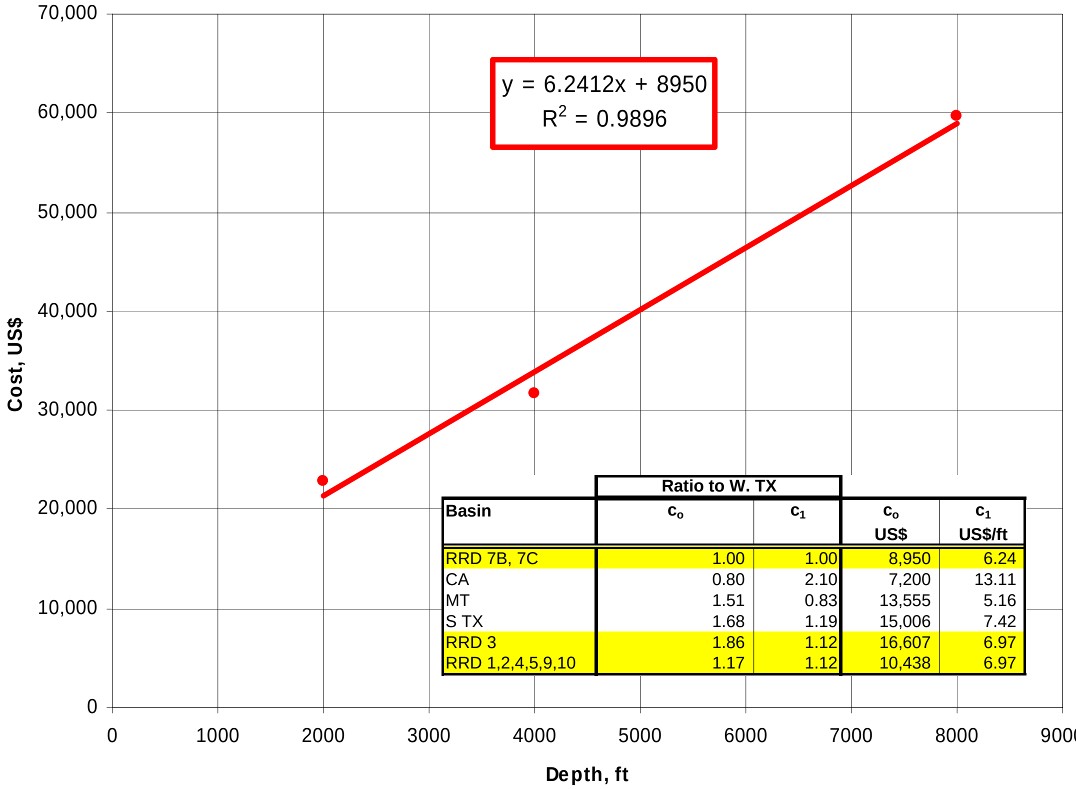
RRD 3 Well Conversion Costs = $c_0 + c_1D$
Where: c_o = \$16,607 (fixed)
c_1 = \$6.97 per foot
D is well depth

RRD 1,2,4,5,9,10 Well Conversion Costs = $c_0 + c_1D$
Where: c_o = \$10,438 (fixed)
c_1 = \$6.97 per foot
D is well depth

RRD 7B, 7C Well Conversion Costs = $c_0 + c_1D$
Where: c_o = \$8,950 (fixed)
c_1 = \$6.24 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 Texas cost equations.

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



Basin	Ratio to W. TX c_o	Ratio to W. TX c_1	c_o US$	c_1 US$/ft
RRD 7B, 7C	1.00	1.00	8,950	6.24
CA	0.80	2.10	7,200	13.11
MT	1.51	0.83	13,555	5.16
S TX	1.68	1.19	15,006	7.42
RRD 3	1.86	1.12	16,607	6.97
RRD 1,2,4,5,9,10	1.17	1.12	10,438	6.97

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 equations for the Texas RRDs are:

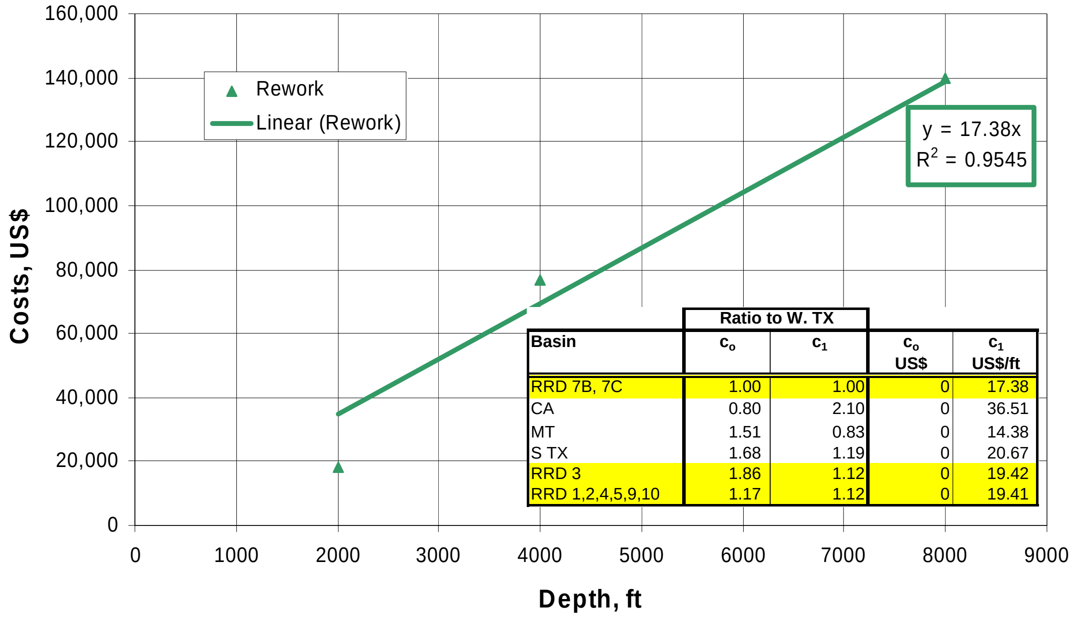
RRD 3 Well Rework Costs = c_1D
Where: c_1 = \$19.42 per foot
D is well depth

RRD 1,2,4,5,9,10 Well Rework Costs = c_1D
Where: c_1 = \$19.41 per foot
D is well depth

RRD 7B, 7C Well Rework Costs = c_1D
Where: c_1 = \$17.38 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 Texas RRD cost equations.

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



Basin	Ratio to W. TX c_o	Ratio to W. TX c_1	c_o US$	c_1 US$/ft
RRD 7B, 7C	1.00	1.00	0	17.38
CA	0.80	2.10	0	36.51
MT	1.51	0.83	0	14.38
S TX	1.68	1.19	0	20.67
RRD 3	1.86	1.12	0	19.42
RRD 1,2,4,5,9,10	1.17	1.12	0	19.41

6. Annual O&M Costs, Including Periodic Well Workovers. The EIA Cost and Indices report provides secondary operating and maintenance (O&M) costs only for West Texas. As such, West Texas and East and Central Texas primary oil production O&M costs (Figure B-6) are used to estimate Texas 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

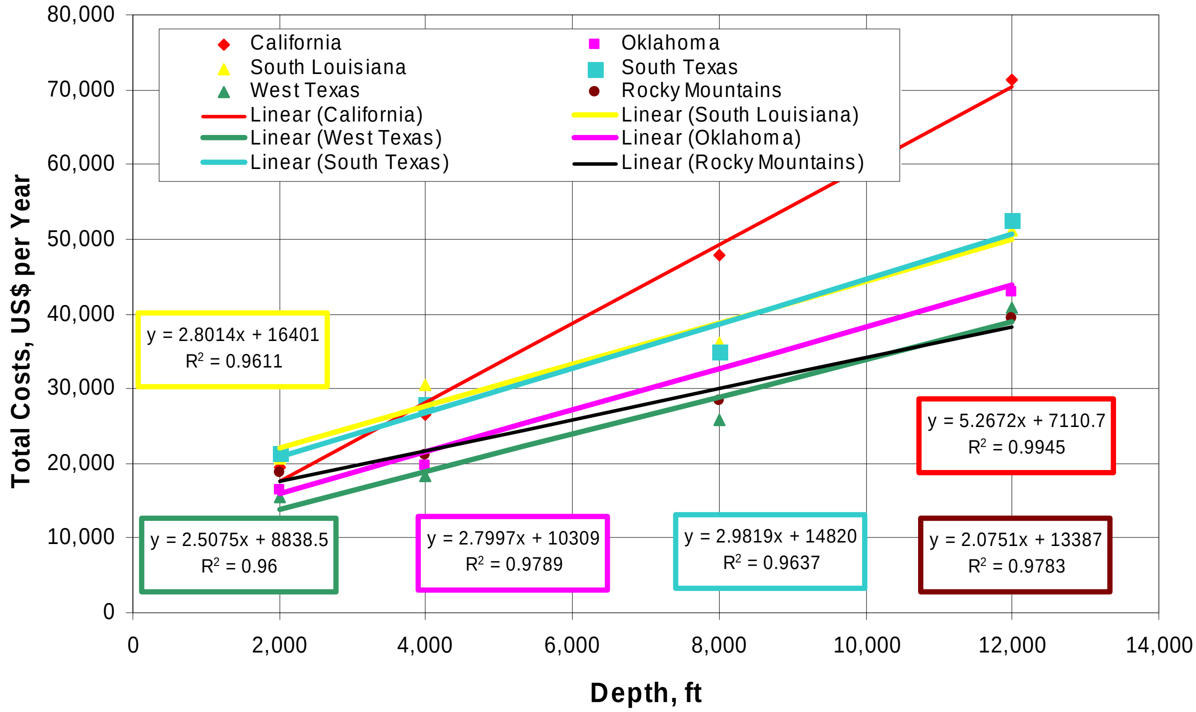


Table B-1. Regional Lease O&M Costs and Their Relationship to West Texas

Basin	c_o US$	c_1 US$/ft	Ratio to W. TX c_o	Ratio to W. TX c_1
RRD 7B, 7C	8,839	2.508	1.00	1.00
CA	7,111	5.267	0.80	2.10
MT	13,387	2.075	1.51	0.83
S TX	14,820	2.982	1.68	1.19
RRD 3	16,401	2.801	1.86	1.12
RRD 1,2,4,5,9, 10	10,309	2.800	1.17	1.12

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 are 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.)

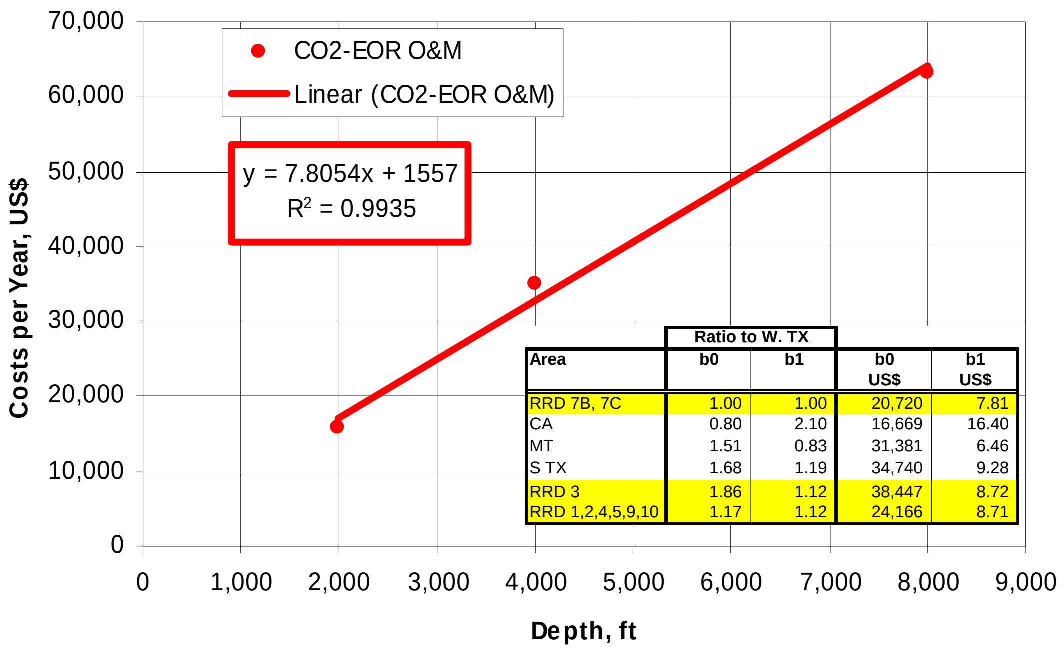
Figure B-7 shows the depth-relationship for CO_2-EOR O&M costs in West Texas. These costs were adjusted to develop O&M for East and Central Texas, shown in the inset of Figure B-7. The equations for the RRD's are:

RRD 3 Well O&M Costs = $b_0 + b_1D$
Where: b_0 = \$38,447 (fixed)
b_1 = \$8.72 per foot
D is well depth

RRD 1, 2,4,5,9 Well O&M Costs = $b_0 + b_1D$
Where: b_0 = \$24,166 (fixed)
b_1 = \$8.71 per foot
D is well depth

RRD 7B,7C Well O&M Costs = $b_0 + b_1D$
Where: b_0 = \$20,720 (fixed)
b_1 = \$7.81 per foot
D is well depth

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



	Ratio to W. TX			
Area	b0	b1	b0 US$	b1 US$
RRD 7B, 7C	1.00	1.00	20,720	7.81
CA	0.80	2.10	16,669	16.40
MT	1.51	0.83	31,381	6.46
S TX	1.68	1.19	34,740	9.28
RRD 3	1.86	1.12	38,447	8.72
RRD 1,2,4,5,9,10	1.17	1.12	24,166	8.71

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

The cost of the recycling plant is set at \$700,000 per MMcf/d of CO_2 capacity. As such, small CO_2-EOR project in the Willamar field, with 39 MMcf/d of CO_2 reinjection, will require a recycling plant costing $27 million. A large project in the Tom O'Connor field, with 795 MMcf/d of peak CO_2 reinjection and 251 injectors requires a recycling plant costing $556 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 COTWO 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 15MMcf/d), $120,000 per mile for 6" pipe (CO_2 rate of 15 to 35 MMcf/d), $160,000 per mile for 8" pipe (CO_2 rate of 35 to 60 MMcf/d), and $200,000 per mile for pipe greater than 8" diameter (CO_2 rate greater than 60 MMcf/d). 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 West Texas 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. Texas has enacted risk sharing actions for enhanced oil recovery. The Texas Code MCA 15-36-303(22) and 15-36-304(6) provide incentives for production tax rate reductions for various projects in Texas including qualified enhanced oil recovery projects. The state charges typically charges an oil production severance tax of 4.6% on all oil production and the discounted rate for EOR projects is 2.3%. However, the provisions of the EOR statute are that if the average price of west Texas intermediate crude oil is above $30 per barrel, the all projects, including EOR must pay the full severance tax. Therefore, in the model, the full 4.6% is charged. A state average ad valorum tax of 2.13% was used. Severance and ad valorum taxes are charged after royalties are taken out.

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 Central Texas (a=+$3.32 per barrel) or East Texas (a=-$1.92 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 Texas is:

Wellhead Oil Price = Oil Price + (+/-$a) – [$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. In addition, some fields within Texas contain very light oil (>45 API). In order to keep the economics of these fields level with the rest of the fields, we imposed a ceiling of 45 API for all fields with lighter oil when applying the Crude Oil Price Differential.