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POST WATERFLOOD CO_2 MISCIBLE FLOOD IN LIGHT OIL FLUVIAL DOMINATED DELTAIC RESERVOIR – PRE-WORK AND PROJECT PROPOSAL

Final Report
June 1, 1993-December 31, 1997

By:
Sami Bou-Mikael

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Texaco E&P
New Orleans, Louisiana

National Energy Technology Laboratory
National Petroleum Technology Office
U.S. DEPARTMENT OF ENERGY
Tulsa, Oklahoma

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II.A INTRODUCTION

II.A.1 Introduction to Work Proposed

II.A.1.1 Rationale for the Project

The Administration's National Energy Strategy (NES) proclaimed as its goal the reduction of United States dependence on foreign oil and a resulting increase in energy security. The NES noted that in the United States since the mid-1980s, the amount of oil consumed has increased while domestic oil production has steadily declined. According to projections, if no new initiative is taken, oil imports will grow to almost 60% of U.S. consumption by the year 2000. Future additions to U.S. oil reserves are not likely to offset fully the projected decline in domestic production. With much of our oil coming from politically volatile regions of the globe, the Administration has proposed a series of initiatives to reduce oil usage and to increase oil production. The U.S. Department of Energy (DOE) Class I Oil Program is designed to encourage oil industry and U.S. Government cooperation in developing cost-effective, innovative technical approaches to tapping our vast reserves of trapped oil. By developing innovative approaches for demonstrating new methods for injecting chemicals, gases, or heat, to overcome physical barriers in the reservoir, it is estimated that an additional 1.3 million barrels per day can be produced by the year 2010.

Texaco feels that the application of CO2 flooding technology will increase domestic recoverable reserves by 2.5 billion barrels in FDD reservoirs, and that horizontal drilling with this process will improve reservoir characterization and overall economics of the project.

With current production levels less than 100 BOPD, the reservoir will be abandoned if advanced technologies are not implemented. Texaco proposes the use of two advanced technologies, that of CO2 flooding and horizontal drilling, as a solution to the producibil'rty problem of a FDD reservoir. This will be the first application of a miscible CO2 flood in a post waterflood FDD reservoir and will be the first horizontal well used as a CO2 injector. These two advanced technologies improved recovery of the mobile and immobile oil in the reservoir.

Texaco supports the objectives of the President's NES. By submitting this proposal, Texaco hopes to play a part in applying new technical approaches to increase U.S. oil production. Texaco offers the site, financial resources, technical expertise in methods for advanced recovery, and many years of experience in research and field demonstrations, to make this effort successful.

II.A.1.2 Overview of the Project

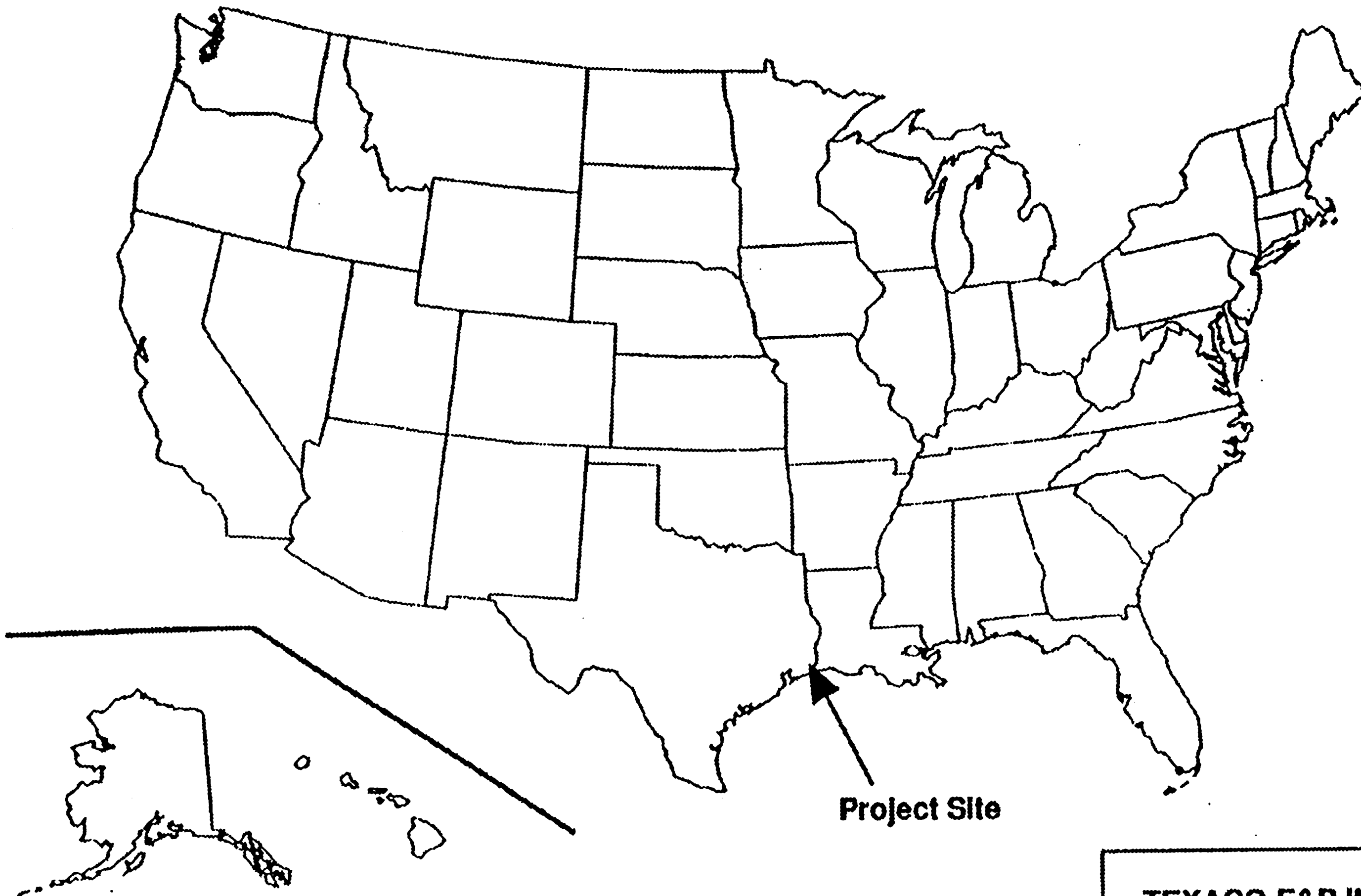
This proposal outlines a project to improve the recovery of light oil from a waterflooded fluvial dominated deltaic (FDD) reservoir through a miscible carbon dioxide (CO2) flood. The site is the Port Neches Field in Orange County, Texas (Figure II.1). The field is well explored and well exploited. The project area is 270 acres within the Port Neches Field (Figure II.2).

In the project area, primary production began in 1934, with waterflood injection beginning in 1965. Primary methods recovered 4.8 million barrels (42%) of the original oil in place (OOIP). The waterflood is projected to recover an additional 1.7 million barrels (15% OOIP) and currently has produced 1.5 million barrels. Projected ultimate recovery for the project area is 6.5 million barrels, or 57% OOIP, by primary and secondary methods.

II.A.1.3 Rational for CO2

Miscible CO2 flooding is an established enhanced oil recovery technology. The technique has been used mainly to recover oil from carbonate reservoirs. Application of the technique to a post-waterflood FDD reservoir with weak aquifer support is an innovative approach with excellent potential for recovery of significant volumes of crude oil.

Production of crude oil from an FDD reservoir is problematic at best. FDD reservoirs are characterized by extreme lateral and vertical variations in porosity and permeability. The zones of low permeability contain a significant percentage of the original oil in place. In reservoirs with a strong water drive, production rates, well spacing, and other engineering techniques can be effectively utilized to ensure that oil is driven out of, or swept, from these zones by the advancing oil / water interface. Excellent recovery is achieved during the primary recovery phase in FDD reservoirs with strong water drives. The small amount of oil remaining in place after primary



TEXACO E&P INC.

Figure II.1 Project Location
PORT NECHES FIELD
ORANGE COUNTY, TX

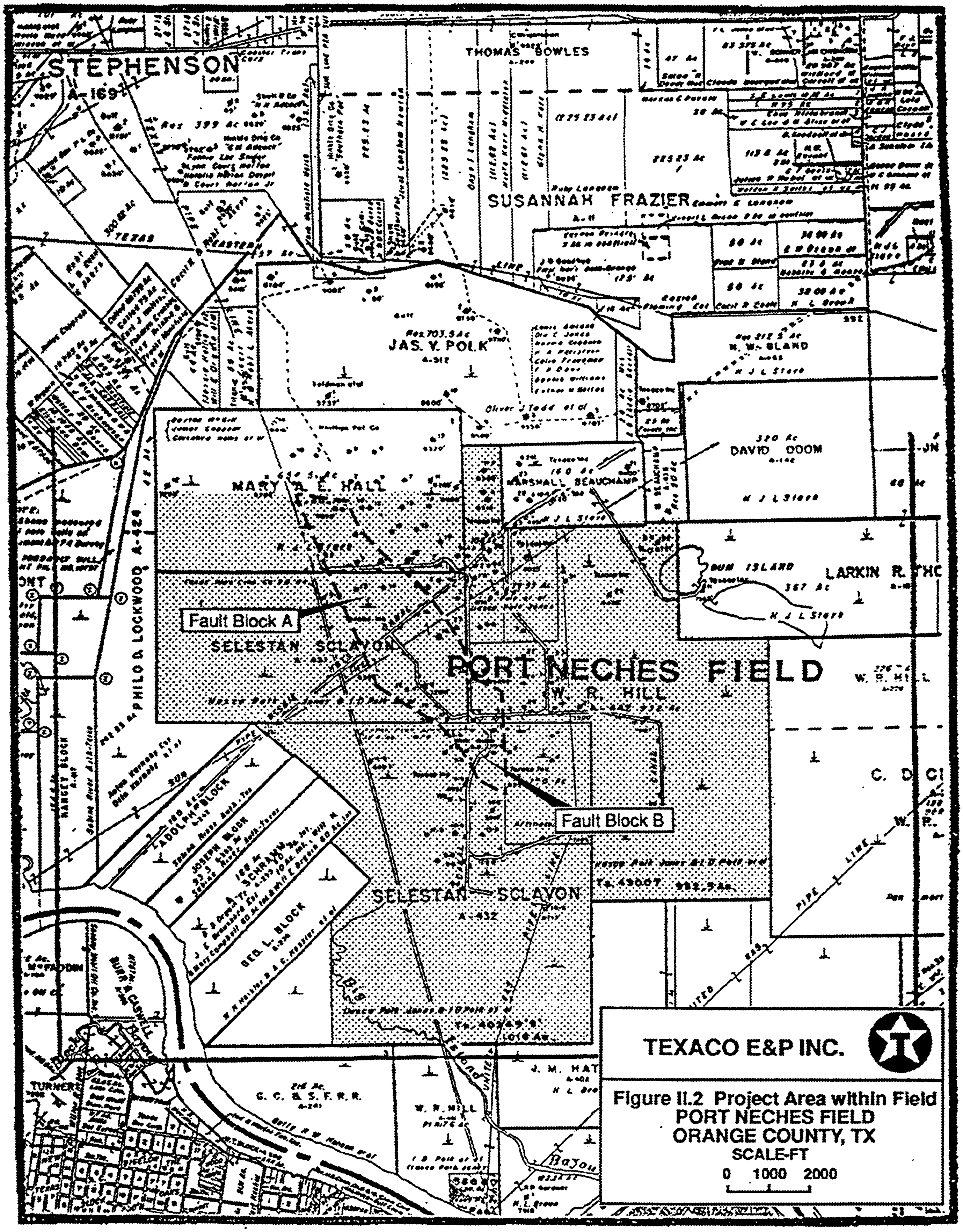


Figure II.2 Project Area within Field
PORT NECHES FIELD
ORANGE COUNTY, TX

recovery is immobile oil, which adheres to the walls of the pore spaces and cannot be moved out of the reservoir by conventional techniques. Although CCL, flooding could effectively mobilize and recover much of this oil, the small overall volume oil remaining in the reservoir after primary recovery makes the technique uneconomical for FDD reservoirs with strong natural water drives.

Oil recovery is significantly less efficient for FDD reservoirs lacking a strong water drive. During primary recovery, pressure depletion is required to mobilize oil through simple expansion and move it to the well bore. Secondary recovery through waterflooding is marginally effective at mobilizing a portion of the oil in the permeable zones, however, channeling in the permeable zones allows premature breakthrough of injected water to producing wellbores. Zones of low permeability are simply bypassed, and large volumes of both mobile oil in these unswept portions of the reservoir, and immobile oil remaining in the permeable zones, are left in place.

CO2 flooding has been employed in FDD reservoirs with no natural water drive to achieve satisfactory recovery rates, however reservoirs of this type are uncommon. The technique has never been tested in a waterflooded FDD reservoir with a weak natural water drive. Reservoirs of this type are common, and supplemental waterflooding has often been employed because it is relatively simple to implement, and economical in spite of its limited effectiveness. Application of miscible CO2 flooding is significantly more complex and expensive, however the great potential for recovery of large volumes of oil left in place in these reservoirs by primary and secondary techniques make the reservoirs extremely viable candidates for miscible CO2 flooding.

An incremental recovery of 19% of the OOIP, or 2.2 million barrels, is estimated for this project. Miscible CO2 will strip and push oil from water-swept zones and from compartments of low permeability where oil saturations remain high, thus increasing the ultimate recovery from both areas of the reservoir. The lower viscosity of CO2 in relation to water allows CO2 to penetrate and sweep compartments of lower permeability. The ability of oil and CO2 to form a single phase (i.e., miscibility) will enable CO2 to entrain and displace oil which cannot be recovered by water from both swept and unswept regions.

The miscible CO_2 flood of the Port Neches Field's Marginulina sand will require raising the current depleted pressure of the reservoir by injection of produced waters to reach CO_2 miscibility at 3310 psia. CO_2 injection at this pressure will allow the CO_2 to mobilize bypassed oil, and formerly immobile oil, through the formation of a miscible CO_2 oil bank. Infill drilling will increase access to reservoir compartments filled with as yet, uncontacted mobile oil. The result is greater flow rates at the producing wells and ultimately more complete recovery of the oil.

Miscible CO_2 flooding of waterflooded FDD reservoirs is a promising technology, but widespread application awaits successful development and demonstration. The Port Neches project is ideal for this development due to several reasons:

- By all measures, Port Neches is very typical of FDD reservoirs. This project will provide a sound basis for generalizing CO_2 flooding results, and will build confidence in applying this technique to other fields.

- The field is well characterized. Port Neches has been a producing field since 1929. The comparatively complete characterization of the field will reduce the up-front costs of this research effort.

- Only three new wells will be drilled, one being a horizontal CO_2 injection well. Of the 15 wells currently at the site, 12 wells will be reworked.

- The project will have little environmental impact. Other than drilling wastes which will be handled in a standard manner, only minimal solid wastes will be generated. Airborne emissions will be minor - well below the levels requiring permits. Produced CO_2 volumes will be dehydrated and reinjected into the reservoir, thus preventing air emissions. Implementation of this project will result in a reduction in CO_2 discharges into the atmosphere, as 4,300,000 scf per day (250 tons per day) of CO_2 will be removed from the vent of a nearby chemical plant.

II.A.1.4 Rational for Project Team

Texaco is a world leader in petroleum exploration and production. We have demonstrated the value of the CO2 flooding technique on other FDD reservoirs. Five of these projects were miscible CO2 floods. Texaco has extensive experience in CO2 injection in carbonate formations in West Texas and in clastic reservoirs in South Louisiana. Texaco's Exploration and Production Technology Division (EPTD) in Houston, Texas, is an industry leader in designing and implementing enhanced oil recovery processes. The company, its researchers, and its laboratories are recognized innovators in methods for enhanced recovery and bring to the project the technical resources essential to its successful completion.

Texaco has chosen SAIC to provide management and administrative support for the proposed project. SAIC is a $1.3 billion technology and management services company serving both government and private industry. SAIC brings to the project extensive knowledge of the energy industry, and a long history of helping both government and the private sector meet their goals in the areas of energy technology development, production, and management.

SAIC is the largest DOE contractor outside the Management and Operations (M&O) arena, providing management and technical support to DOE Headquarters, Field Offices, and Technology Centers. SAIC provides technical and environmental support to the domestic oil industry through its offices in Midland, Texas, McLean, Virginia, and other locations throughout the U.S. SAIC also has hands-on experience in the government-industry cost sharing arena, providing management services and support for an ongoing $22 million project.

We believe the Texaco - SAIC Team provides a combination of technical excellence and management expertise that cannot be surpassed.

II.A.1.5 Rationale for Government Involvement

This project is expected to result in the recovery of 2.2 million barrels of oil at an average production rate of 800 barrels per day. Given this outcome, CO2 injection of a post-waterflood

FDD reservoir will be a viable technology to be used for additional oil recovery. Careful engineering and economic analysis of this advanced technology, has lead Texaco to conclude that success in this effort is likely, but that outside investment is necessary to mitigate the risk inherent in the initial application of the technology. Government cost sharing will make it feasible to explore this innovative method at a scale and at a site which will clearly demonstrate its viability, providing a foundation for the commercial application of the method in other fields.

A 1979 State of Louisiana report "Secondary and Pressure maintenance operations in Louisiana," indicates that 443 reservoirs in Louisiana have been water-flooded. These reservoirs, having approximately 4.3 billion barrels of oil originally in place (OOIP), have ultimate recoveries estimated at 48% OOIP. This leaves a target oil of 2.3 billion barrels, of which approximately 50% may be recovered by utilizing CO2 technology. With this being only a small portion of the depletion and partial waterdrive reservoirs in Louisiana, this state alone is felt to have in excess of one billion barrels of CO2 recoverable reserves.

Description of Project:

Texaco proposes a miscible CO2 flood of the light oil (API gravity 36.9°), fluvial dominated deltaic (FDD) Marginulina sandstone reservoir at the Port Neches Field in Orange County, Texas. This process will be enhanced by the utilization of a horizontal CO2 injection well.

Purpose

A miscible CO2 flood of a waterflooded FDD sandstone reservoir will increase the reservoir's recovery efficiency by using an innovative approach. The remaining mobile oil in the reservoir is compartmentalized by the heterogeneities within the reservoir. Texaco feels that these areas of high oil saturation have not been swept by the 26-year ongoing waterflood in the field, and can be contacted by CO2 and produced at commercial rates. An integrated, multidisciplinary approach to this producibility problem, involving improved reservoir characterization and sweep efficiency by the use of a horizontal CO2 injection well, has led Texaco to believe that a significant opportunity exists in these FDD reservoirs. By developing and demonstrating these methods at Port Neches, Texaco will make new techniques available to the domestic oil industry to recover oil more efficiently from FDD reservoirs.

General Approach / Technology

FDD reservoirs often have poor primary recoveries as a result of limited aquifer support and complex reservoir heterogeneities. Reservoir pressures drop because of limited aquifer support, resulting in depletion of the reservoir energy. As a result of the dissipated reservoir pressures, waterfloods are often attempted to recover additional oil from these reservoirs. Texaco has found, however, that in FDD reservoirs, gas channels develop in the reservoir which allows injected water to break through to the producing wells prematurely. This results in poor secondary recoveries, leaving large volumes of mobile and immobile (residual) oil remaining in the reservoir. Texaco believes that the Port Neches miscible CO2 flood can demonstrate that there is a viable option to continued abandonment of these reserves.

The Port Neches miscible CO2 flood project has been designed to develop and test a superior advanced technology on a reservoir with great incremental recovery potential. Some areas of the reservoir are swept down to the residual oil saturation; but, bypassed other areas of the reservoir have high remaining oil saturations. This non-uniform distribution of oil is a direct result of the FDD nature of the reservoir. Texaco recognizes that a detailed reservoir characterization must be performed to evaluate the recovery efficiency achievable in FDD reservoirs using any new recovery process. By drilling a horizontal CO2 injection well, Texaco will be able to characterize the reservoir rock throughout the entire horizontal section and will be able to sweep large amounts of previously immobile oil.

Continuous injection of CO2 at miscible pressure will be undertaken in the Marginulina sandstone reservoir. Miscibility pressure will be achieved by repressuring the reservoir with produced saltwater. CO2 injection wells will be drilled at the original oil/water contact; and CO2 delivered from a nearby chemical plant, will be used to recover an additional 2.2 million barrels of oil that cannot be recovered by continued waterflood operations.

Anticipated Results

It is anticipated that this project will show that the application of miscible CO_2 floods, after waterfloods in weak aquifer FDD reservoirs, can be economically implemented to recover substantial bypassed mobile and previously immobile oil.

By applying horizontal drilling technology to the enhanced oil recovery processes, improved reservoir characterization and sweep efficiencies can be achieved. This process will preserve a substantial resource that is otherwise at risk of abandonment. In the project area, a 19% incremental increase in oil recovery is anticipated, totalling 2.2 million barrels versus the 200,000 barrels currently recoverable by waterflood. Texaco estimates that up to half of the remaining oil in the Gulf Coast trend, may be recoverable through application of this process to weak aquifer, waterflooded FDD reservoirs.

II.B. PROJECT DESCRIPTION

The proposed project is described in three parts. First an overview of the project is provided with an emphasis on the reservoir characteristics and proposed recovery technology. Second, we describe the site, including location, characteristics unique to this site, surface facilities, and other relevant data. The third and final section is a detailed technical description, which covers (1) the producibility problem; (2) the reservoir characterization needed to design, manage, monitor, and evaluate the process; (3) the existing and planned reservoir characterization data and interpretation techniques; (4) the proposed oil recovery process, including process chemistry and the influence of reservoir materials on the process; (5) the innovative aspects of the proposed recovery process; and (6) the measures that will be used to calculate the improvement over current technology.

II.B.1. Overview

The Port Neches Field demonstration will use miscible CO2 to recover an additional **2.2** million stock tank barrels of oil (MMSTBO) that cannot be recovered by continued waterflooding operations because of the architecture of the reservoir and the characteristics of the oil. Minimum miscibility pressure will be achieved before CO2 injection by injecting produced waters into the reservoir during 1992 and early 1993 to raise the reservoir pressure from the current level of 1850 psig to 3400 psig. CO2 will then be injected into the Marginulina reservoir to mobilize the remaining oil that cannot be recovered by water displacement. This process will be enhanced by the use of a horizontal CO2 injection well drilled at the original oil/water contact. Reservoirs with weak aquifers leave behind large quantities of oil. Because of their facies variations and compartmentalization, FDD reservoirs have areas that remain virtually unswept. Reservoir characteristics can be used to identify areas of high remaining oil saturation in previously produced FDD reservoirs. Miscible CO2 may be able to significantly improve recovery of bypassed mobile and immobile oil from FDD reservoirs that have been waterflooded. CO2 miscible floods have not been performed and evaluated in this reservoir environment (see Table II.1).

Table II.1

Incremental Recovery Efficiency by Process in Fluvial Dominated Deltaic Reservoirs

RESERVOIR TECHNOLOGY	EFFICIENTY WHERE STRONG AQUIFER PRESENT	EFFICIENCY WHERE WEAK OR NO AQUIFER PRESENT
PRIMARY	Excellent	Fair to Good
WATERFLOOD	Not Appropriate	Poor to Fair
CO2 FLOOD AFTER PRIMARY	Fair	Fair to Good
CO2 FLOOD AFTER WATERFLOOD	Not Appropriate	Unknown (The objective of this proposal)

The project area covers 270 acres. Primary and secondary production has recovered 6.3 million barrels of oil out of 11.4 million, leaving a 33% average oil saturation. Continued water-flood operations will recover an additional 200,000 barrels of oil, but will leave behind substantial amounts of remaining oil in the reservoir at imminent risk of abandonment. The application of a CO2 flood after waterflood has not been previously attempted in an initially weak aquifer FDD reservoir that has been waterflooded. This project can illustrate an economical means of recovering this depleting resource. The proposed demonstration is expected to recover 2.2 million barrels of oil or 19% of OOIP that would otherwise be abandoned (see Table II.2).

Table II.2

Basic Milestones in the Port Neches Field Development

- Field discovery date: 1929
- First Marginulina Production: 1934
- Onset of Marginulina Waterflood: 1965
- Predicted Onset of Pilot Marginulina CO2 Rood: First CO2 injection is anticipated for August, 1993.

Proposed Project Area:

- Marginulina OOIP: 11.4 million barrels
- Cumulative Marginulina Production to Date: 6.3 million barrels
- Remaining Resource Recoverable by Waterflood: 200,000 barrels (2% of OOIP)
- Incremental Recovery Anticipated from Implementation of the CO2 flood:
  2.2. million total barrels (19% of OOIP)

II.B.1.1. Summary of Reservoir Characteristics

Beginning in mid-1991, Texaco began work in reservoir characterization and process design for a miscible CO2 flood at the Port Neches field. We have identified large volumes of oil in place within the Marginulina sands. Based on the characteristics of the Marginulina reservoir and the recent advances in the understanding of CO2 technology, Texaco is proposing a field demonstration in which CO2 is used to recover (1) unswept oil that remains after waterflood operations and (2) immobile oil trapped within the pore spaces of the swept areas of the reservoir.

The Marginulina sand in the Port Neches Field was deposited in an FDD reservoir environment where a dominant river source was not confined to a single channel. As channels migrated and channel abandonment occurred, the coarser-grained, higher-permeability channel sands graded upward through time into finer-grained, lower-permeability deposits.

This upward fining characteristic is manifested in the gamma ray, spontaneous potential, and resistivity logs. The other depositional features that are present, typical of the lower delta plain of a fluvial dominated delta, include (1) overbank facies that also appear as upward fining sections on logs (2) delta plain facies that include the shale facies with interfingering lignites and occasional thin sands that are manifested on the logs by the rattiness of the section. (Where lignites are present, the gamma ray is similar to that of a shale, but neutron and resistivity traces have distinct spikes.)

The Marginulina sand within the project area is dominantly characterized by an upward fining sequence typical of abandoned channel and overbank deposits. In a highly constructive delta (dominated by the river system), the delta front has prograding distributary mouth bars deposits. These are present in the field, as well. They are characterized by upward coarsening deposits.

The sand is compartmentalized in a manner consistent with the porosity and permeability variations expected in an FDD reservoir. Port Neches Field's Marginulina sand reservoir has, on average, high porosities (30%) and high permeabilities (750 md). The limits of the reservoir are defined by large faults and oil/water contact. Table II.3 lists various reservoir characteristics within the project area and their relationship to FDD reservoirs in general.

II.B.1.2. Summary of Proposed Recovery Technology to Be Demonstrated

This project will demonstrate that, where remaining oil saturation is high because of the characteristics of the reservoir, significant increases in the cumulative production from a weak-aquifer FDD reservoir can be accomplished by injecting CO2 at miscible pressure.

Miscible CO2 will displace additional oil that cannot be recovered by water-flood in an FDD reservoir through two distinct tertiary recovery mechanisms: (1) oil vaporization in water swept zones and (2) oil banking in low permeability compartments with high remaining oil saturations.

Saturation distribution of compartments within waterflooded, weak-aquifer reservoirs range from the original 80% to irreducible oil saturation to water of 20%, due to uneven sweep. This is often a function of where the water is being injected. In FDD reservoirs, the injected water often never has an opportunity to contact the oil because of the particular characteristics of the reservoir which cause channeling. On the other hand, CO2 contacts these unswept areas of the reservoir while creating additional reservoir energy by expansion of the oil in place. The oil is forced into the high permeability channels, thus allowing the producing wells to flow at high rates. Waterdrive reservoirs, on the other hand, have no expansion capability because water and oil are immiscible.

The miscible CO2 flood of Port Neches Field's Marginulina sand will require that we raise the current depleted pressure of the reservoir by injecting produced waters to reach a CO2 miscibility of 3310 psia. CO2 injection at this pressure will allow the CO2 to mobilize bypassed oil and formerly immobile oil by forming a miscible CO2 oil bank. Infill drilling will increase access to reservoir compartments filled with as-yet uncontacted, mobile oil. A horizontal well drilled along the original oil/water contact of the reservoir will allow for the sweep of a large amount of residual oil over a great distance. This proposed recovery technology permits connection of isolated

compartments through additional infill drilling, reduction of irreducible oil saturation through miscibility with CO_2, and displacement of formerly immobile and bypassed oil with CO_2.

II.B.2. Site Description

II.B.2.1. *Location of Site*

The location of Texaco's proposed field demonstration is 3 miles northeast of the town of Port Neches in Orange County, southeastern Texas. The project area is within the Port Neches Field (also known as the Bessie Heights Field). The approximate center of the project area is at 30° 02'N latitude and 93° 56'W longitude. Texaco has chosen a demonstration site covered by three leases: (1) J. V. Polk-B-, (2) H. J. Kuhn (Tracts 1&2), and (3) W. H. Stark-B-. The leases are contained in the following Texas surveys:

Selestan Sclavon A-432 (J. V. Polk-B-); Selestan Sclavon A-431 (H. J. Kuhn Tract 1); W. R. Hill A-442 (H. J. Kuhn Tract 2); and Mary A. E. Hall A-403 (W. H. Stark-B-).

The target reservoir is the Marginulina sand at a depth of approximately 6000' subsea.

Other producing horizons in the field include the Miocene, Frio, and Hackberry formations.

The 270-acre project area has 15 wells that penetrate the Marginulina sand. Two wells are currently being used as water injection wells, five wells are producing wells, six wells are shut-in, and two wells are completed in other reservoirs. Numerous other wells exist outside of the project area but within the field.

Fault Block A:

The large waterflooded fault block is 240 acres. Texaco recovered 5.7 million barrels of oil out of 10.0 million, with an additional 200,000 barrels to be recovered.

Table II.3

Reservoir Characteristics

RESERVOIR CHARACTERISTIC	FDD RESERVOIRS	MARGINULINA SAND PORT NECHES FIELD
Pay Thickness	Fluvial dominated deltas are non-uniform, have variety of subenvironments, examples of average pay thicknesses (i.e. not net): Distributary Channels - 60' Distributary Mouth Bars - 99' Crevasse Splay Channels - 33'	Within the project area, net pay ranges from 0' to 38' with an average of 33'.
Porosity	Porosity can vary from less than 5% to as much as 40% both within facies and between facies. Porosity varies both vertically and aerial.	Range is 23% to 34%, average is 30%.
Fluid Saturation	Oil, gas, and water will vary from 0 to 100%	The original oil saturation is 80%, and even after a successful waterflood, there are a significant number of compartments that are at the original oil saturation. There is little free gas in the reservoir.
Irreducible Oil Saturation	Usually an average is determined for the entire reservoir of approximately 25%. However, based on clay content, gas content, and type of depositional feature, the irreducible oil saturation can be as high as 50%.	Post waterflood, is established to be 20%.
Oil Viscosity	Variable	Original 0.97 cp Current 2.40 cp with CO_2 0.51 cp
Permeability	Permeability varies considerably both aerial and vertically. FDD reservoirs display abrupt changes in permeability, which allows displacing fluids to form channels from the injectors to the producing wells.	Permeability varies between 25 md and 1500 md. Current average is 750 md, subject to revision by new data. Specific high-perm flow channels within the project area have caused mobile oil to be bypassed by the current waterflood.
Depth	Up to 25,000 feet	Approximately 6000 feet
Pressure	Variable, dependent on depth or abnormal pressuring.	Initial pressure: 2,700 psia. Current reservoir pressure: 1850 psia. CO_2-oil miscibility pressure: 3310 psia.
Dykstra-Parson Coefficient	0.3 to 0.7 with average 0.5	0.5

Fault Block B:

The smaller fault block is 30 acres. We recovered 600,000 barrels of oil out of 1.4 million, with only 5,000 barrels to be recovered from ongoing operations.

The CO2 project will require that three additional wells be drilled in this reservoir and that twelve of the existing wells be worked over. The new wells will be CO2 injectors, one of which will be a horizontal well approximately 1500 feet of horizontal displacement. The workover wells include all five currently producing wells, five of the six shut-in wells, one of the two injection wells, and one well completed in a different reservoir. This well will be plugged down to the Marginulina reservoir.

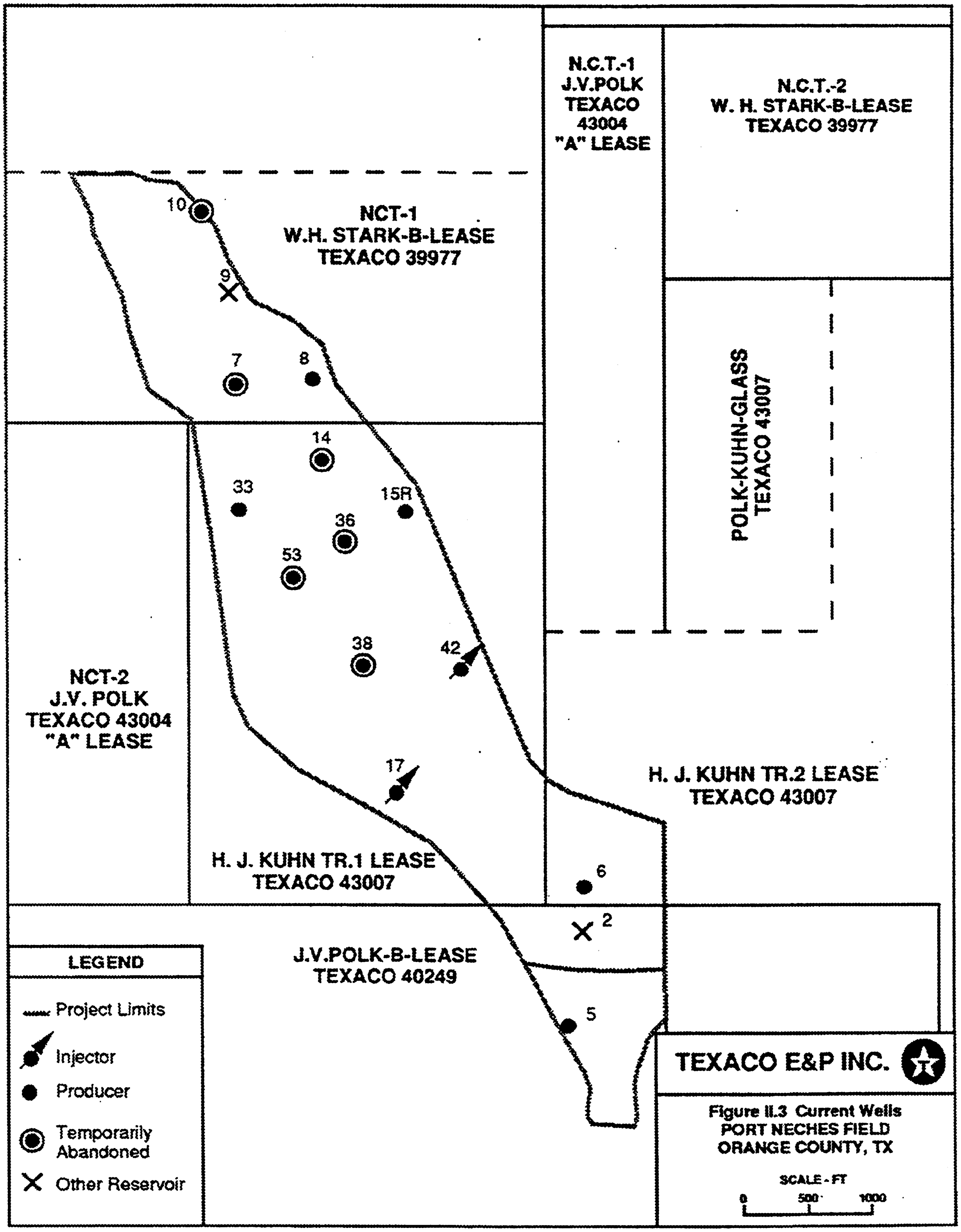
Project design calls for six CO2 injection wells and nine producing wells. One injection well will no longer be completed in the Marginulina reservoir. One existing well will remain shut-in. One well, completed in another reservoir, will not be involved in the project. There will be no wells exclusively designated as observation wells. The location of the existing and proposed wells are shown on the accompanying two maps, Figures II.3 and II.4.

II.B.2.2 - Site Characteristics

The project site is located in inland waters at a depth of 3 to 8 feet. The wells and facilities are accessed through a series of canals that were dredged out of the swamps. The service canals are connected to the Bessie Heights Canal, which runs northeast to southwest through the center of the Port Neches Field. Bessie Heights Canal is the primary public thoroughfare, and it connects the town of Bessie Heights to the Neches River.

II.B.2.3 - Surface Facilities

Surface facilities that will be installed for the miscible CO2 flood are shown in Figure II.5 and include a CO2 injection pump, recycle booster compressor site with two compressors, water handling facility with a larger saltwater injection pump, production tank battery, gathering lines, injection lines, gas lift lines, and an additional oil transportation line. (See Figure II.6 also).



N.C.T.-1
J.V.POLK
TEXACO
43004
"A" LEASE
N.C.T.-2
W. H. STARK-B-LEASE
TEXACO 39977
NCT-1
W.H. STARK-B-LEASE
TEXACO 39977
POLK-KUHN-GLASS
TEXACO 43007
NCT-2
J.V. POLK
TEXACO 43004
"A" LEASE
H. J. KUHN TR.2 LEASE
TEXACO 43007
H. J. KUHN TR.1 LEASE
TEXACO 43007
J.V.POLK-B-LEASE
TEXACO 40249
10
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53
38
42
17
6
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5
LEGEND
Project Limits
Injector
Producer
Temporarily Abandoned
Other Reservoir
TEXACO E&P INC.
Figure II.3 Current Wells
PORT NECHES FIELD
ORANGE COUNTY, TX
SCALE - FT
0
500
1000

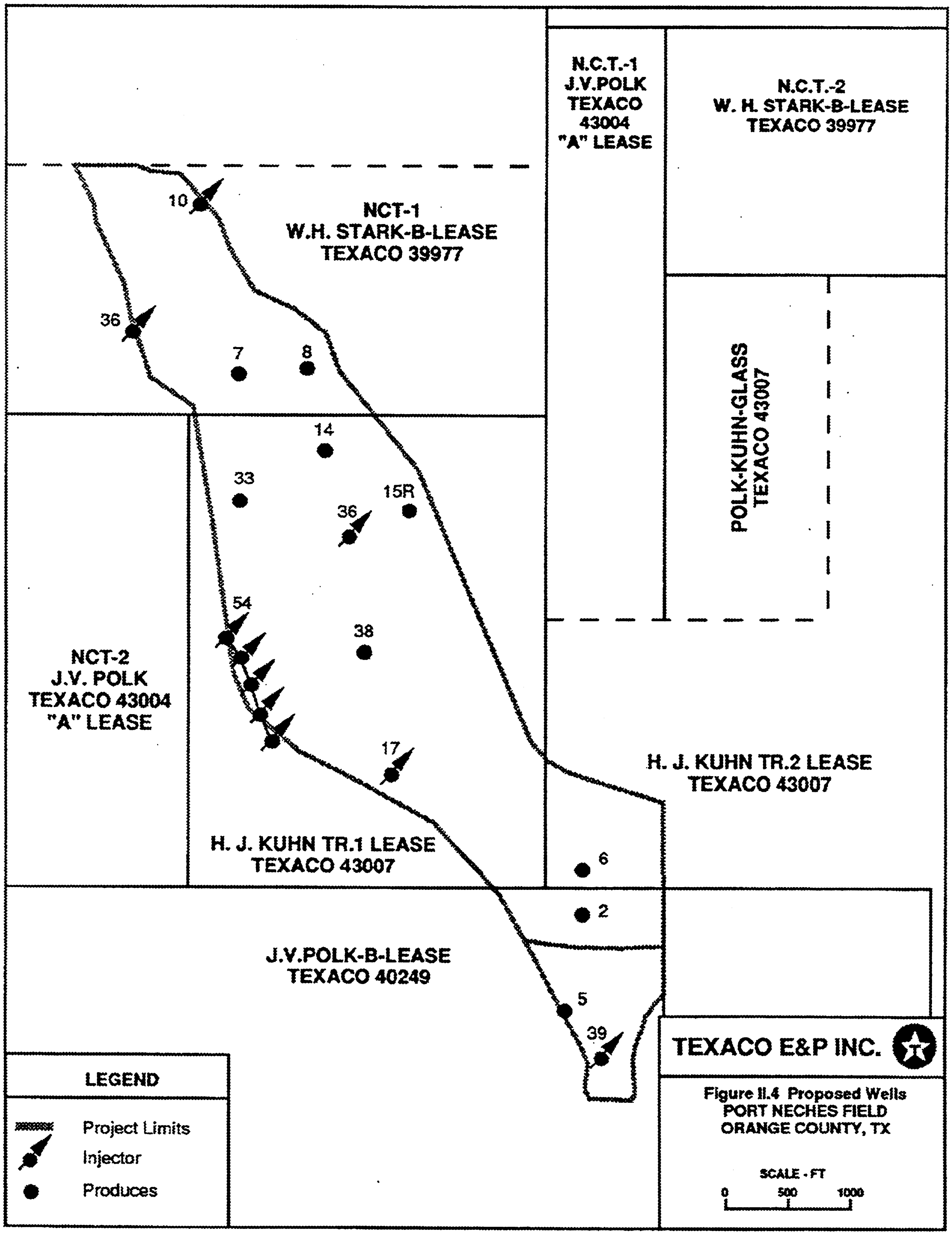
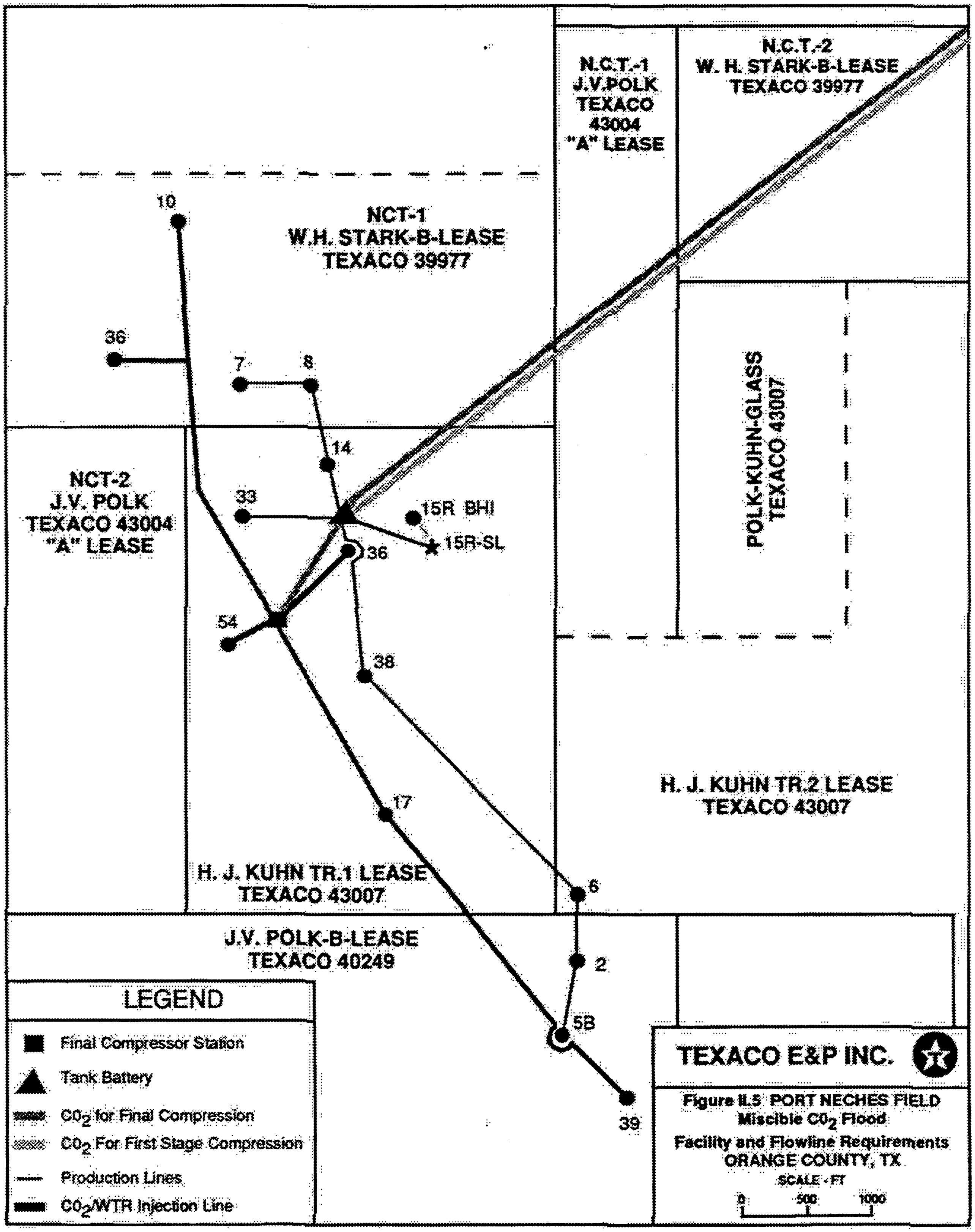


Figure II.4 Proposed Wells
PORT NECHES FIELD
ORANGE COUNTY, TX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J.V.POLK
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"A" LEASE
N.C.T.-2
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NCT-1
W.H. STARK-B-LEASE
TEXACO 39977
POLK-KUHN-GLASS
TEXACO 43007
NCT-2
J.V. POLK
TEXACO 43004
"A" LEASE
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15R-SL
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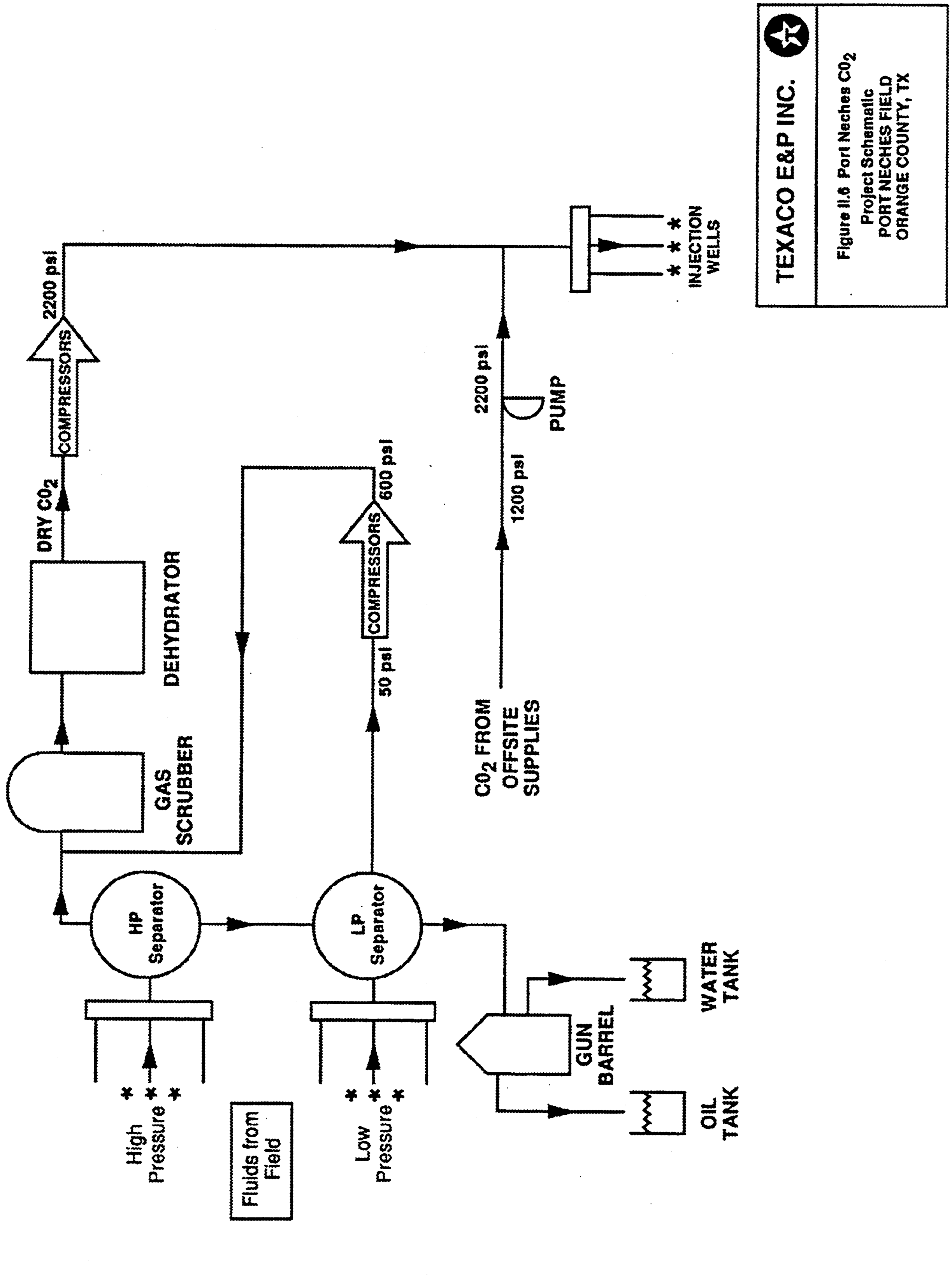
5B
39
H. J. KUHN TR.2 LEASE
TEXACO 43007
H. J. KUHN TR.1 LEASE
TEXACO 43007
J.V. POLK-B-LEASE
TEXACO 40249
LEGEND
Final Compressor Station
Tank Battery
CO_2 for Final Compression
CO_2 For First Stage Compression
Production Lines
CO_2/WTR Injection Line
TEXACO E&P INC.
Figure II.5 PORT NECHES FIELD
Miscible CO_2 Flood
Facility and Flowline Requirements
ORANGE COUNTY, TX
SCALE - FT
0 500 1000



TEXACO E&P INC.
Figure II.6 Port Neches CO_2 Project Schematic
PORT NECHES FIELD
ORANGE COUNTY, TX
High Pressure
Low Pressure
Fluids from Field
HP Separator
LP Separator
GAS SCRUBBER
DEHYDRATOR
DRY CO_2
COMPRESSORS
2200 psi
50 psi
600 psi
CO_2 FROM OFFSITE SUPPLIES
1200 psi
PUMP
INJECTION WELLS
GUN BARREL
WATER TANK
OIL TANK

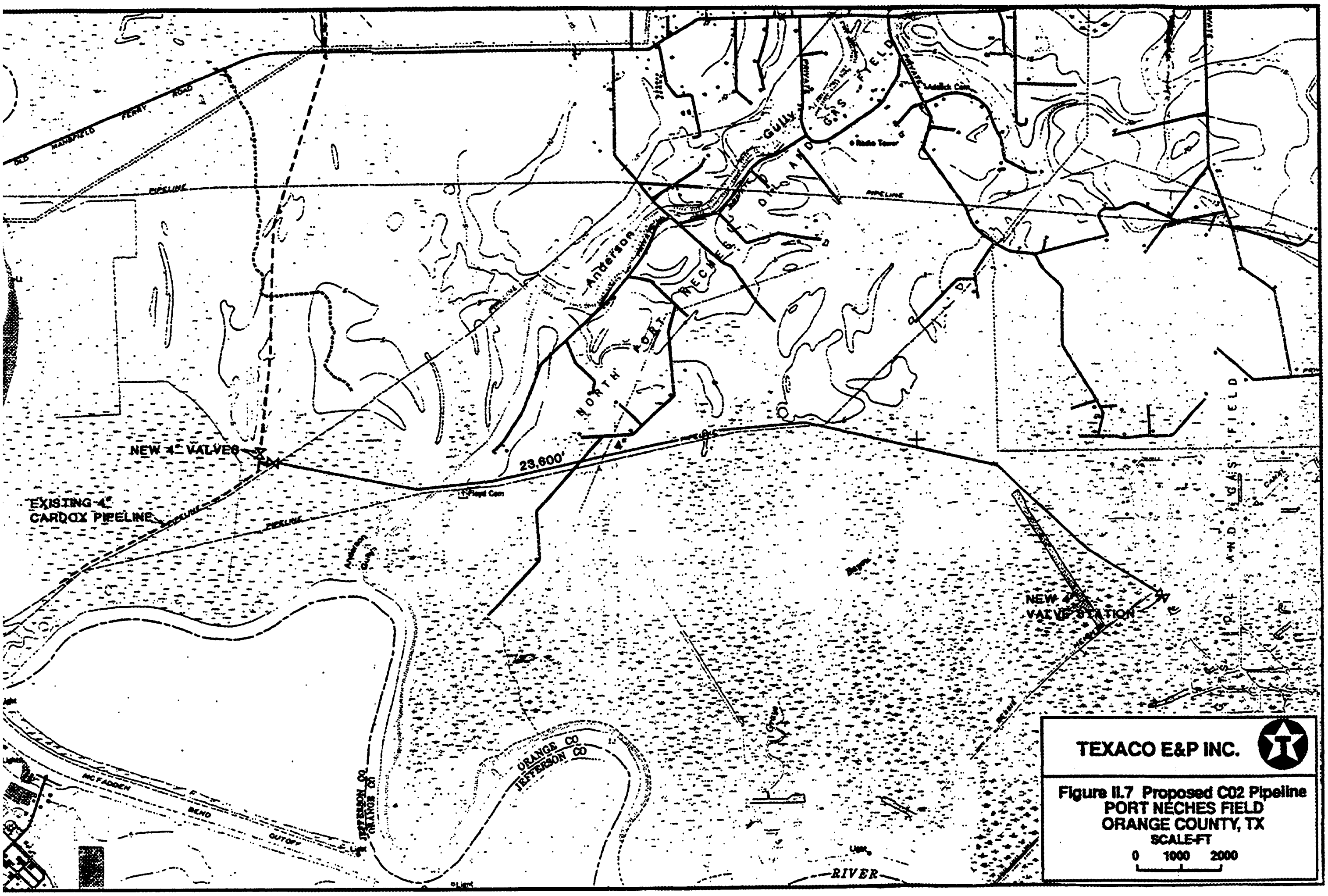
A 4.5 mile, 4 inch CO2 pipeline will be installed from the CO2 supplier's pipeline to a new CO2 compressor and pump site located in the field (Figure II.7). This pump will be used to boost the pressure of the incoming CO2, from 1200 psia to injection pressures of approximately 2200 psia. A small 330-HP compressor will be set at this compressor site to pick up incoming intermediate pressure CO2 gas at 500 psia and compress it to 2200 psia. Based upon a pressure gradient of 0.183 psia per foot, the bottomhole pressure will be 3300 psi. A larger compressor will be set during 1994 to handle additional volumes of intermediate pressure CO2, gas.

Reservoir pressure will be raised beginning in 1992 by injecting large amounts of produced saltwater, including water produced from other sources in the field. A water handling facility must be installed, and all water in the field will be rerouted to this central location. A larger saltwater disposal pump capable of moving larger volumes of water at higher discharge pressures will be installed.

A new tank battery will be built with 6-500 bbl oil storage tanks and corrosion-protected separation equipment. This new facility is required not only because of the corrosive nature of the produced fluids, but because all production from the project area must be kept separate from other field production due to different mineral ownership of the leases. This new tank battery will have gas and liquid measurement equipment that will allow for individual testing of wells. Safety monitoring equipment will also be used to ensure safe operation of the facility.

Production and injection wells will require that new flowlines be laid to the wells. These lines will be corrosion-protected lines. Some inactive producing wells will require that high-pressure gas lift lines be laid to allow production to be reestablished.

A 7000' low pressure (75 psi) gas gathering line and a 7000' intermediate pressure (600 psi) return line will be installed from the new tank battery to an onshore compressor. This compressor will require repairs during 1993 to equip it to handle CO2 gas. Low pressure gas will be compressed from 50 psi to 550 psi and returned via this return line to the field compressor site.


TEXACO E&P INC.
Figure II.7 Proposed C02 Pipeline
PORT NECHES FIELD
ORANGE COUNTY, TX
SCALE-FT
0 1000 2000
NEW 4" VALVES
EXISTING 4" CARDOX PIPELINE
23,600'
NEW 4" VALVE STATION
Anderson
NORTH PORT NECHES
ORANGE CO
JEFFERSON CO
RIVER
PIPELINE

When the transfer point of the oil sales is changed, additions will be required to the oil transportation lines.

II.B.2.4. Other Relevant Information

The proposed research program will require coordination between four of Texaco's offices, one of SAIC's offices and various DOE offices. The team members offices are shown on Figure II.8 and described below.

Texaco's Field Office

The field operating personnel are located in a field office that is 1.5 miles from the project site at the end of the Bessie Heights road. These eight people (including the field production foreman, head roustabout, four roustabouts, a pumper, and a relief pumper) receive management support from the Sour Lake area office in Sour Lake, Texas. The Sour Lake Area employs a total of 155 employees. Responsibilities include financial management of production operations, workover supervision, and coordination and implementation of field activities.

Texaco's Engineering Office

The CO2 Asset Management Team is located in Texaco's Harvey, Louisiana, office. The Asset Management Team provides engineering design and reservoir simulation support for the CO2 projects. A project design engineer and reservoir simulation engineer will be dedicated to the Port Neches Field project. Division management personnel for Texas properties are located in downtown New Orleans.

Texaco's Laboratory

Laboratory work will be performed by Texaco's Exploration & Production Technology Division located at the Briarpark and Bellaire facilities in Houston, Texas. These facilities employ approximately 600 individuals. Of the technical staff 35% have doctorates, 25% have master's degrees, and 40% have bachelor's degrees. Of the technical personnel, 27% have at least 20 years of service with Texaco, indicating that we have an experienced workforce. The facility is separated into six operational groups; enhanced oil recovery, geological research support, drilling and production technology, measurement and flow technology, reservoir engineering, and geophysics.

TEXACO E&P INC.

Figure 11.8 Project Offices & Locations PORT NECHES FIELD ORANGE COUNTY, TX

Texaco's Regional Offices

Legal, accounting, environmental, geology, and senior engineering staffs are located in Texaco's New Orleans office. Texaco's Eastern Regional office, responsible for the management of Exploration and Production, is located in New Orleans, and employs approximately 3200 individuals throughout Louisiana, Texas, Mississippi, and Alabama. Among these, about 1400 are members of the Onshore Producing Division.

Science Applications International Corporation (SAIC) Administration and technical support provided by SAIC will be performed by their System Engineering and Analysis Division located in the McLean, Virginia, offices. SAIC has a long history of providing support to both government and industry in the coordination and administration of government programs. The first stage of production in the Port Neches Field Marginulina sand was primary recovery through pressure depletion (1934 to 1965). Depletion allows gas to come out of solution when pressure drops below the bubble point. The bubble point for the reservoir is estimated to be 2550 psia. During the depletion phase of recovery, the reservoir

II.B.3. Detailed Technical Description

II.B.3.1. Discussion of Producibility Problem

The producibility problems to be resolved include channeling and the high mobility of water relative to that of the remaining oil in the reservoir (i.e., the high mobility ratio that exists in FDD reservoirs that have undergone pressure depletion and subsequent waterflooding). These reservoirs have significant remaining mobile and immobile oil saturations because of their complex reservoir heterogeneities and the immiscibility of oil and water. Texaco plans to address these producibility problems and to demonstrate a viable method to recover the bypassed mobile and previously immobile oil within these reservoirs through the application of a miscible CO2 process.

An average of 63% of the oil remains in FDD reservoirs (DOE, 1991). Many of these reservoirs, particularly those along the Gulf Coast, are depletion drive reservoirs that have undergone secondary waterflood operations. Texaco has performed over 60 waterfloods in South Louisiana, many of which were economically unsuccessful. Waterflooding bypasses much of the mobile and immobile oil because of the permeability variations within the rock. High remaining mobile oil saturations exist where oil has been uncontacted or bypassed by channeling. (See Figure II.9).

The first stage of production in the Port Neches Field Marginulina sand was primary recovery through pressure depletion (1934 to 1965). Depletion allows gas to come out of solution when pressure drops below the bubble point. The bubble point for the reservoir is estimated to be 2550 psia. During the depletion phase of recovery, the reservoir pressure dropped from 2700 psia to 100 psia. As a result, the viscosity of the remaining oil in the reservoir increased from 0.97 cp to 2.4 cp and the gas/oil ratio increased from 500 to 6,000 scf/bbl. In the absence of a strong waterdrive and as a result of the pressure drop within the reservoir, a gas cap was formed that has subsequently been produced. As a result of the reservoir architecture, oil saturation has remained as high as the initial 80% in some reservoir compartments. The oil saturation decreased from an initial 80% to an average of 50% by 1950, in the swept regions of the reservoir. During this primary recovery stage, communication between wells was identified, and specific non-communicating fault blocks were determined by bottomhole pressure tests, enabling a secondary recovery process to be implemented. The second stage in the development of the Marginulina sand reservoir of the project area was secondary recovery using a waterflood displacement process (1965). Waterflood design located injection wells in a pattern to sweep the remaining mobile oil in the reservoir. Two wells were located at the original oil/water contact.

An initial design of a waterflood may consider a uniform permeability distribution throughout the reservoir. This is almost never the case in FDD reservoirs. The deposition processes related to sedimentation in a fluvial dominated delta create a highly heterogeneous reservoir environment. Sand/silt/clay ratios vary widely within the formation and even within the individual sand compartments. Point bars, distributary mouth bars, and overbank (crevasse splay) facies contain

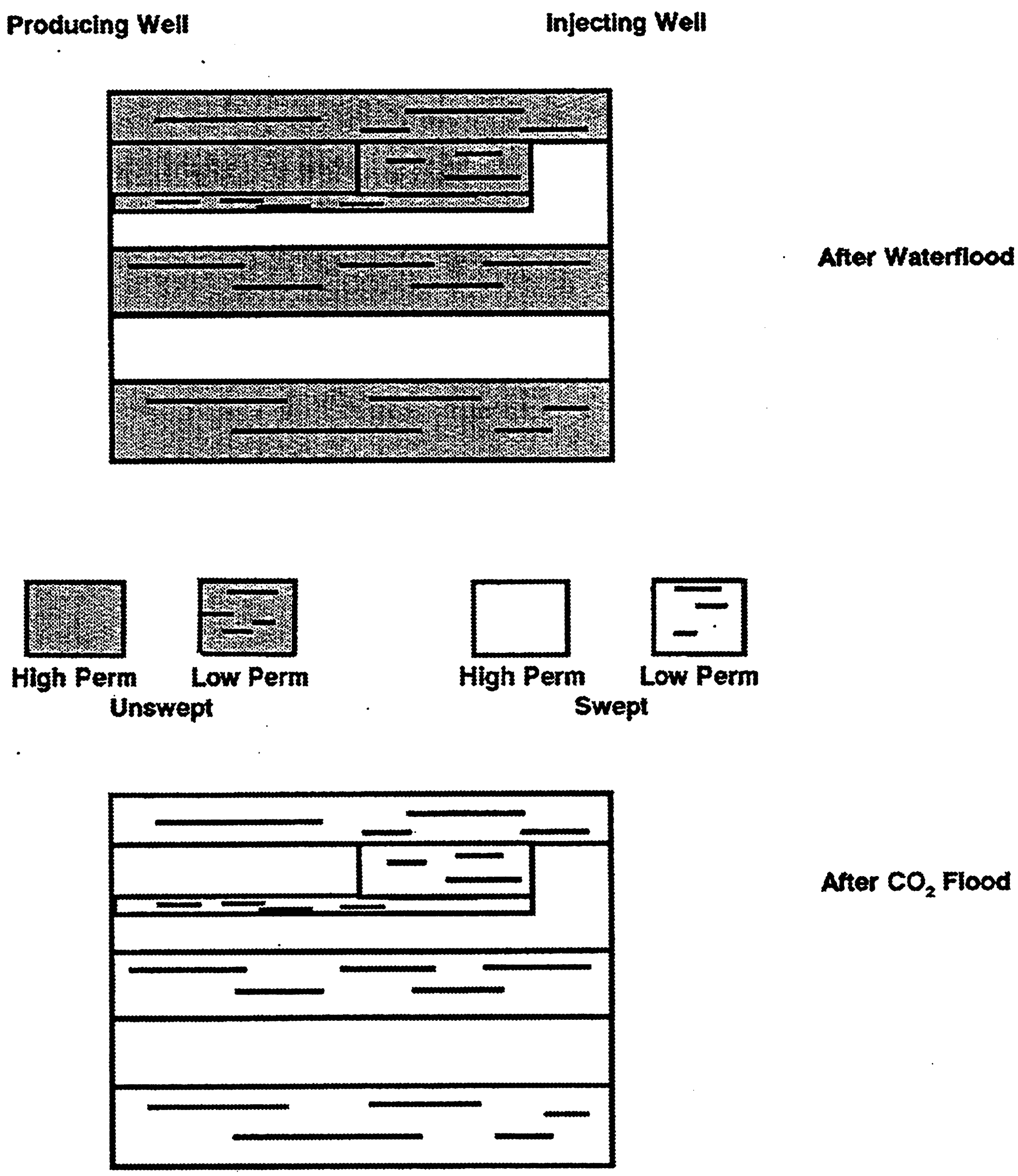


Figure II.9 Sweep Efficiency by Process in a Heterogeneous Reservoir. (Vertical scale in 10's of feet and horizontal scale 1000's of feet.)

highly permeable zones that allow channeling of the injected water. In areas where the flow energy of rivers/waters depositing the sediment were dissipated (marshes, delta fringe, edges of splays), finer grained deposits form lower permeability compartments that remain unswept by the injected water, which follows the higher permeability channels. Clay swelling can further restrict the displacement process by restricting the movement of water in pore throats in both high and low permeability areas.

Although an average recovery efficiency (primary plus secondary waterflood) of 59% of OOIP was determined for the project area from decline curve analysis and volumetric calculations, sweep efficiencies by this immiscible process are poor in many areas within the heterogeneous FDD reservoir. The oil saturation currently averages 35%, but many compartments contain much higher oil saturations. Breakthrough occurred quickly, indicating high permeability zones. Water injection tended to bypass much of the existing oil as a result of the high mobility of water in the higher permeability flow channels. The high permeability channels can be identified by production profile analysis (volume and watercut changes over time). Compartments with high remaining mobile oil saturation can be identified with reservoir characterization studies, and areas where infill wells might be drilled can be located. However, infill drilling alone is rarely undertaken in these reservoirs because the high drilling costs are not justified by the modest incremental recovery. Texaco has recovered incremental mobile oil by waterflood in the project area, but a significant volume of mobile and immobile oil has been bypassed. This is consistent with industry wide performance of waterfloods in FDD reservoirs.

CO2 is a viable alternative to an immiscible waterflood process in these types of reservoirs. As a result of the miscible nature of CO2 with oil, greater sweep efficiency will be realized than that achieved through displacement by water. The mobility ratio, which is currently 2.5, will be reduced to 0.5, with CO2 injection recently in a greater sweep efficiency on individual sand compartments as

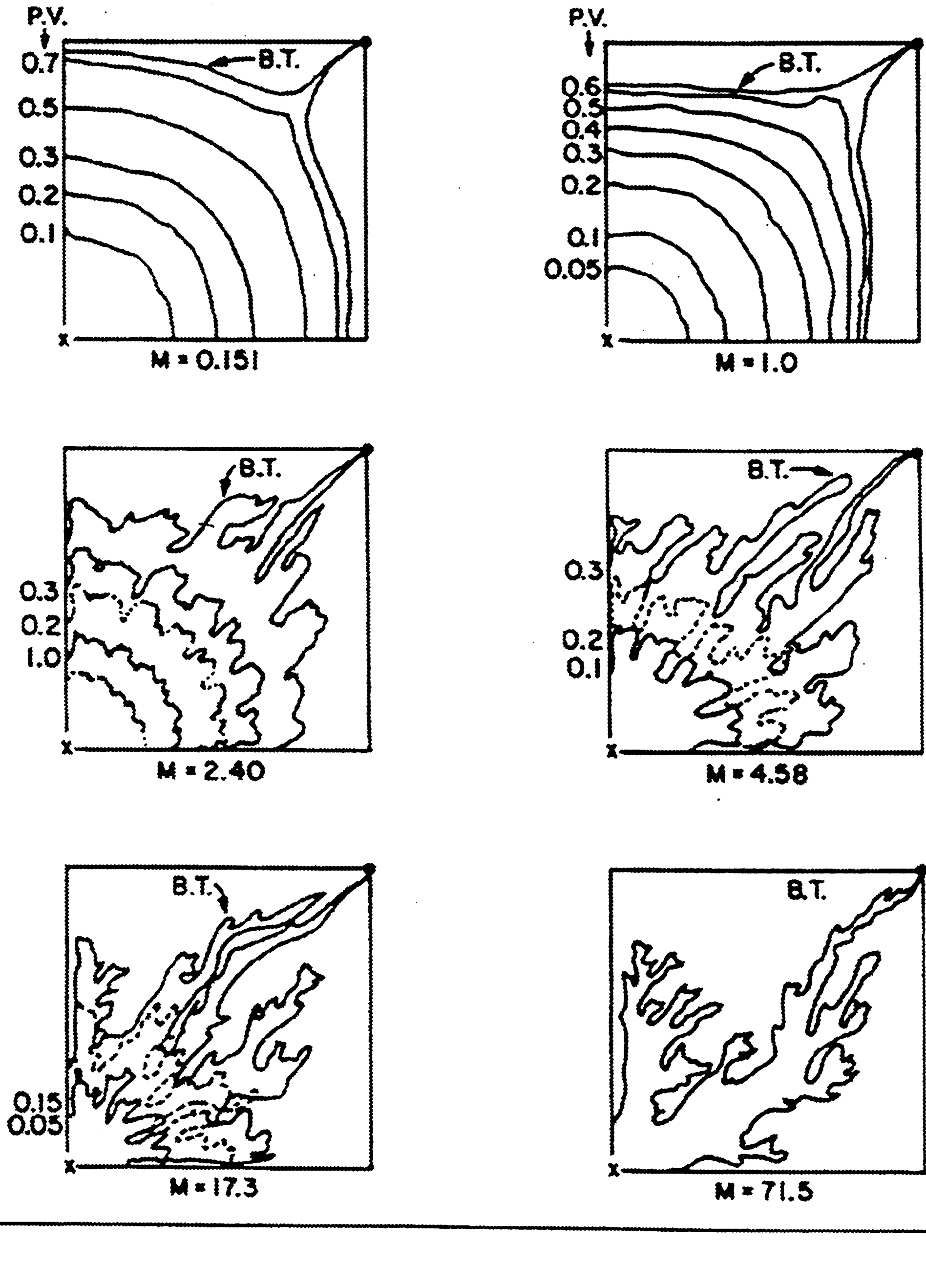


Figure II.10 Areal Sweep Efficiency for Different Mobility Ratios and Injected Pore Volumes until Breakthrough (after Haberman, 1960). Port Neches Project waterflood mobility ratio = 2.50, CO_2 Flood = .90.

shown in Figure II.10. In addition, CO_2 will mobilize residual immobile oil that water cannot displace and will entrain and displace it.

II.B.3.2. Reservoir Characterization

Reservoir characterization is necessary to design, manage, monitor, and evaluate the proposed advanced technology process. An integrated multidisciplinary approach using geological, geophysical, and engineering data has been and will be used to understand the interaction of the reservoir architecture and the recovery process.

The reservoir characterization required to design the project has been completed. Additional data will be acquired and interpreted in the implementation phase, which will aid in reservoir management and in monitoring and evaluating the recovery process.

The reservoir characterization (both engineering and geologic) necessary to design, manage, monitor, and evaluate the proposed advanced technology process is defined below. Reservoir characterization data and interpretation techniques are also described, including the existing characterization and our plans to acquire and interpret additional reservoir data during the course of the project.

Depositional Theory and Paleontology

Texaco must apply depositional theory (geologic) to interpret all available reservoir data. Depositional theory may be defined as those concepts that combine the knowledge of transport processes and ancient environments to determine the configuration of sediments. The result is an understanding of sedimentary facies, including their internal architecture and spatial relationships. A geologic evaluation of the project area was undertaken and will be expanded. The objectives of this study are to (1) determine the environment of deposition of the reservoir, (2) determine the structural character of the reservoir, (3) define the reservoir boundaries, (4) examine the stratigraphic relationships of the reservoir sand(s), (5) determine the continuity of the reservoir, (6) predict the spatial distribution and probable trends of observed porosity and permeability data, and (7) describe the nature of all reservoir heterogeneities.

In the design phase depositional theory has been used to:

- determine depositional environment,
- optimize the placement of infill wells, including use and placement of a horizontal well,
- estimate heterogeneity type to be encountered in infill wells, and
- create new maps and cross-sections from reexamined data (including structure and net oil sand isopach).

The results of applying this theory during the design phase were that:

- faults were located to determine the boundaries of the reservoir,
- continuity was examined, and
- paleontological reports were examined to determine paleoenvironment (environment of deposition - water depth, salinity, deposition energy, etc.)

Seismic Data

Fault location was conducted by reviewing existing seismic structure maps and extensive subsurface well data. As a result, Texaco has defined the project area boundaries with a high degree of confidence. Although not planned as part of this proposal, acquisition of 3-D seismic data may be considered at a later date for this field. Texaco has been a leader in the development of improved seismic data acquisition, processing, and interpretation for many years. Considerable effort has been devoted to extending our ability to extract meaningful information under the most difficult conditions. This includes applying geophysical methods to exploration and development in complex geologic settings such as the Marginulina Sand in the Port Neches Field, which is a highly faulted, piercement salt dome.

Engineering aspects of reservoir characterization build on knowledge of rock characteristics (porosity, permeability, bed thickness and continuity, grain size), production performance (decline, volumes, composition), pressure behavior (changes in reservoir pressure, communication between wellbores), fluid properties (oil/gas/water saturations, viscosity, compositional evaluations, miscibility pressure, vaporization pressure), and the nature of fluid flow (water breakthrough, viscosity, rate) to model the reservoir and simulate the recovery process within the constraints of the reservoir. Geologists and engineers work closely to model the distribution of reservoir characteristics accurately in order to enhance production and/or ultimate recovery.

Electric/Radioactive Logs

Complete reservoir definition on a macroscopic scale is emphasized with formation evaluation. Well logging, well testing, and nondestructive core analysis are used as evaluation techniques. To manage the reservoir, including monitoring and evaluating the process, detailed information on the reservoir architecture will be gathered and evaluated.

Well log analyses in the design phase were used to identify and characterize sand bodies. The physical reservoir characteristics (rock and fluid properties) were determined, including porosity, temperature, oil saturation, volume, reserves, oil-water contacts, net and gross sand thickness, sand distribution, heterogeneity (sand/shale ratios, facies changes), and dip. Maps and cross-sections were generated using these data.

A complete suite of logs will be run in new wells. These will include a Dual-Induction Focused Log, Formation Compensated-Density Log, Compensated-Neutron Log, Dipmeter, Gamma Ray Log, and Spontaneous Potential (SP) Logs. Standard log evaluation techniques will be used. Interpretations of reservoir characteristics, geologic and engineering, will be modified with data from the new wells. A dipmeter will be run to determine dip in the reservoir. The progress of the injectant through the reservoir (fluid movements) will be monitored with Pulsed Neutron Logs.

Core Evaluation

Nondestructive core testing uses methods like X-ray computed tomography (CT), which is revolutionizing core analysis as it did medical diagnostics will be considered. A fourth-generation CT instrument with very sophisticated computer imaging has been installed at Texaco's research facilities and is now operating. Whole core analysis of density, porosity, fracture porosity, and lithology (chemical composition and structural heterogeneity) are among Texaco's in-house capabilities.

Nuclear magnetic resonance imaging (NMRI or MRI) is being applied to formation evaluation at Texaco's research facilities. It is the complement of X-ray CT. NMRI sees only the fluids in the rock, and CT sees primarily the rock. Texaco is developing NMRI to determine quickly the oil/water saturations in core material. In the design phase, sidewall cores were prepared and analyzed to assess reservoir quality; production, depositional and diagnenetic models; andlithology and porosity distributions. The rock characteristics, permeability, porosity, and oil/gas/water saturations were described. High- perm zones were identified.

Cores, sidewall cores, and sample cuttings will be gathered from new wells and will be used to modify earlier evaluations as part of the continuing monitoring and evaluation tasks. Texaco's Research Center will run special core analyses on conventional core. Relative permeability, residual oil saturation, and current saturation will be determined.

Fluid Chemistry Tests

Fluid chemistry tests are used in the design monitoring and evaluation phases of this project. Characterization of the reservoir fluids determined API gravity, viscosity, and oil/water ratios. Tests run on live oil determined the equation-of-state for the initial reservoir crude. Fluid characterization in the process design phase analyzed CO2 reservoir oil phase behavior and yielded minimum miscibility (slimtube test) and optimum vaporization pressures for reservoir crude. Constant composition expansion tests were run on live oil to better understand CO2 reservoir oil phase behavior. Swelling/solubility and viscosity reduction experiments with CO_2 on the stock tank oil were also conducted. The equation-of-state for the original reservoir crude using live oil was determined.

Texaco will monitor the compositional changes of the produced fluids (i.e., API gravity, CO_2 contamination) to detect changes in the oil (vaporization) and gas produced (to monitor the mixture composition to maintain miscibility).

Pressure Tests

Bottomhole well pressure tests and pressure buildup tests were used to determine that no communication existed across the faults and to determine near borehole permeability and skin factors. These will continue to be run across field on a routine basis.

Tracer Surveys

Communication between existing wells will be investigated using tracer surveys. Radioactive tracers (different ones at different wells) will be added to the injectant to monitor fluid movement through the reservoir. Texaco plans on running an extensive tracer program to analyze the effects of heterogeneity in these reservoirs. These tracer programs will also be used to monitor flow paths developed within the reservoir. The progress of the fluids through the heterogeneous reservoir will be observed by Pulsed Neutron Logs in producing wells. Periodic CO_2-oil bank maps will be drawn to show the movement/displacement of oil within the reservoir; the maps will also be used with depositional theory to understand the internal reservoir architecture. Injectivity surveys will be run in the injection wells and will indicate whether the CO_2 is penetrating the entire sand. Sand layers with higher permeability should show a preferential movement of CO_2.

Simulation and Reservoir Modeling

Extensive reservoir simulation and modeling work has been performed. Modified CO2PM and COMPIII models have been run. Material balance analyses were performed with an in-house computer model. OOIP and the aquifer influx constants were determined. A modified version of

DOE's C02PM program has been used to analyze production sensitivities to reservoir characteristics. C02PM input and results were applied to COMPIII, a compositional reservoir simulation model. A relative permeability curve was developed. The COMPIII model produced a match on total oil recovered from the project area, thereby obtaining an average current oil saturation. The simulation will be refined based on new core data and reservoir description.

II.B.3.3. Explanation of Proposed Oil Recovery Process

The advanced oil recovery process of miscible CO2 flooding centers around the ability of injected CO2 to contact the reservoir oil and form a single phase within the reservoir. The pressure at which this phenomenon occurs is the minimum miscibility pressure. Texaco has measured this pressure in the laboratory for the Port Neches reservoir crude oil and has found that the reservoir pressure must be maintained above 3310 psia to achieve miscibility. Although CO2 is not usually miscible with reservoir oil upon initial contact, CO2 may create a miscible front within the reservoir by vaporizing light components of the reservoir crude. In this case, CO2 saturates the reservoir fluids to an extent that the reservoir oil swells and becomes miscible with the enriched *CO2*. In the laboratory, the Port Neches reservoir crude has been shown to swell 70% in the presence of 70 mole percent *CO2*. Oil viscosity is also reduced 47% when this same mole percent CO2 is injected into the reservoir fluid.

A miscible CO2 flood of the Port Neches Field's Marginulina FDD reservoir will add approximately 7 years to the producing life of the reservoir and will increase its ultimate recovery by 2.2 million barrels. Texaco has designed a continuous (i.e. no WAG) CO2 injection process for this reservoir, during which high pressure CO2 will be injected into the reservoir at pressures above the minimum miscibility pressure (MMP) of the reservoir crude. With reservoir pressure currently below the MMP of 3310 psia, produced saltwater will be injected in the reservoir at high rates beginning in 1992 to raise the reservoir pressure from 1850 psia to about 3400 psia. This will allow production to begin as soon as CO2 can be piped to the field.

The Port Neches Field was selected as a prospective CO2 candidate during 1990, based upon the readily available nearby CO2 sources and the reservoirs depletion drive recovery mechanism used as the primary recovery process. Two high quality (i.e., no nitrogen contamination) CO2 sources were within 5 miles of the Port Neches Field, which allowed Texaco to evaluate these sources for their cost effectiveness. The depletion drive primary recovery process in the reservoir is attractive because of the inherently poor primary recovery efficiencies obtained in these FDD reservoirs. The unique application of CO2 flooding in a post-waterflood FDD reservoir would also allow us to obtain additional knowledge about recoverable reserves by designing, implementing, and monitoring such a process. Texaco's past inability to recover substantial reserves through waterflooding these types reservoirs also indicates that major benefit could be achieved by proving that a different process would work in these depletion FDD reservoirs.

An extensive economic examination of available CO2 sources in the area has allowed Texaco to reach an agreement in principle with a nearby CO2 supplier. This CO2 supplier recovers 4.3 million cubic feet per day (MMCFPD) of CO2 from a chemical plant's vent near Beaumont, Texas, and compresses the recovered CO2 from 20 psia to 1200 psia. This compressed CO2 will be transported via pipeline to the Port Neches Field. After arriving in the field, the CO2 pressure will be raised from 1200 psia to 2200 psia by a CO2 pump. CO2 will be initially injected into five separate wells and into a sixth beginning in 1994. CO2 will enter the reservoir at a pressure above the minimum miscibility pressure and will contact the reservoir oil. The injection pattern will be a modified five-spot pattern, because of the irregular spacing of wells in the reservoir, and production will be made from existing wells.

The continuous CO2 flooding process was chosen over the Water Alternating Gas (WAG) process because it was felt that the many benefits associated with continuous CO2 flooding outweighed those associated with the WAG process. The ability to maintain continuous flow from wells in these high permeability reservoirs outweighs the minimal advantages of improved sweep efficiencies associated with the WAG process. Also the WAG process would require that an artificial lift (e.g., gas lift, submersible pump, or rod pump) be employed during times when the wells would not flow. Gas lift gas causes contamination to the CO2 stream and is difficult to prevent. Beam pumps are difficult to regulate on wells that periodically flow. Submersible pumps are susceptible to corrosion and are not recommended for high gas/oil ratio applications.

Continuous CO2 injection allows contact with more immobile oil by sweeping and removing all of the reservoir fluids that the CO2 contacts. Water often prevents CO2 from contacting the oil that is located in the reservoir compartments that are separated by reservoir heterogeneities. Continuously injecting CO2, "dries up" the reservoir so that the next pass of CO2 that moves through the reservoir can contact the immobile and mobile oil that was previously bypassed. Because of the irregular well spacing patterns common to FDD reservoir field development, the benefits of WAG processes are limited by the inability to regulate waterflow injection in reservoirs without patterned injection.

Regarding the influence of reservoir materials (i.e., reservoir rock) on the CO2 flooding process there is felt to be insignificant interaction between the reservoir rock and the *CO2.* CO2 in contact with the reservoir waters will, however, form carbonic acid. When this acid contacts downhole and surface tubulars, it is extremely corrosive. Proper material design will minimize this production problem.

II.B.3.4. Innovative Aspects of Proposed Process Technology

The innovative aspects of the Port Neches Field CO2 miscible flood center around the theory of compartmentalized oil saturation distribution within a waterflooded FDD reservoir that has undergone pressure depletion during the primary recovery phase of production. Operators have focused on CO2 flooding of strong waterdrive reservoirs along the Gulf Coast for a number of years, because the pressures in these reservoirs often exceed the minimum miscibility pressure of the reservoir crude. Through previous CO2 floods conducted in strong waterdrive reservoirs in the

Paradis and Bay St. Elaine fields in South Louisiana, Texaco determined that insufficient remaining oil saturations exist in these type reservoirs to economically produce them at today's oil prices. This uniform sweep across the entire limits of the reservoir has swept the reservoir down to residual oil saturations throughout. Sufficient energy exists in a strong waterdrive reservoir which prevents free gas from breaking out of solution in the reservoir, also increasing sweep efficiency of the process. Strong waterdrive reservoirs achieve a much higher sweep efficiency than waterflooding, due to uniform and extensive bottom water influx from the aquifer, versus isolated water injection locations in water-floods.

Another major innovation to this project is the application of a horizontal CO2 injection well. This well will be drilled along the original oil/water contact of the reservoir, and will allow for the injection of CO2 over a 1500' distance. Reservoir characterization can be made over a 1500' section of the reservoir, as opposed to a 33' section common to a vertical well. Formation cuttings will be collected on a foot by foot basis, and an analysis made on their grain structure size and shape. This horizontal well will not only eliminate the need to drill an additional well, but will also improve sweep of the residual oil column of the reservoir. A vertical well's injection pattern follows streamlines to the producing wells, thus bypassing additional oil. With the horizontal well, a more uniform CO2 front can be established.

Depletion drive reservoirs that have been waterflooded have substantially more producible mobile oil than do strong waterdrive reservoirs, because when reservoir pressure is below the bubble point poor recovery efficiencies occur during waterflooding. Gas channels that exist in the reservoir before waterflooding, cause premature water production and incomplete sweep. Because of the architecture common to FDD reservoirs, much oil is left in isolated compartments and is not reached by waterflood operations. If the CO2 process is used to repressure the reservoir and to force the free gas back into solution, a much more efficient recovery procedure can be achieved.

In summary, CO_2 flooding of a post-waterflood FDD reservoir has not been previously performed. Continuous CO_2 injection processes have been applied to other types of reservoirs, however, they have only been applied in a limited number of reservoirs whose pressures are initially below their minimum miscibility pressure. Texaco's innovative approach to reservoir characterization-which examines the depositional environment to develop a porosity and permeability distribution across the field, will aid in advanced oil recovery techniques.

II.B.3.5. ***Benefits (improvement in oil recovery and CO2 applicability)***

in the field. Texaco feels that successful completion of this project will help the oil industry realize the importance of improved reservoir characterization techniques. Improvements in the character definition of the rock within the reservoir provides an optimized CO_2 project design and monitoring program, improved description of porosity, permeability, relative permeability, fluid properties, and reservoir boundaries will be achieved using advanced technological procedures. As new wells are drilled, reservoir characterization data can be updated, which will improve the matching of primary and secondary production histories. Fault boundaries will be updated by using 3-D seismic techniques (not included in this proposal). Advances in compositional simulation will be made, and a screening process for FDD reservoirs will be developed.

Additional improvements in the oil industry's perception of the CO_2 miscible flooding process will result from Texaco's technology transfer efforts. This CO_2 recovery process in post-waterflood FDD reservoirs will demonstrate that CO_2 flooding has better sweep efficiency than does water-flooding. Continuous CO_2 injection of FDD reservoirs will be economical because of the recovery of large amounts of remaining oil that is trapped in the reservoir. Although CO_2 flooding of sandstone reservoirs requires substantial compression, many of the producibility problems will be eliminated by repressuring the reservoir to avoid gas channeling problems that are present at low reservoir pressures. This process also eliminates the need for artificial lift.

The horizontal well technology applied to this project will improve the sweep efficiency by contacting the residual oil column over a 1500' horizontal section. The ability to inject CO_2 at all points along the horizontal section will provide a CO_2 front as opposed to a single point source. In vertical injectors, the CO_2 follows the pressure sinks toward the producing wells. The horizontal well will allow the CO_2 to contact the oil along the entire face of the residual oil column, prior to reaching the producing wells. This will improve recoveries from the project, and at the same time, reduce the number of injectors necessary to perform the task. This continuous CO_2 flooding procedure will prove the economic viability of recovering the remaining oil in these FDD reservoirs, which would result in a reduction in number of abandoned wells in prospective reservoirs.

II.C. TECHNICAL READINESS

II.C.1. Current Status of Reservoir Characterization

Within the proposed project area, Texaco has already begun characterizing the reservoir to gain an understanding of the nature of the heterogeneities and flow paths within it. Geologic and engineering data have been gathered, analyzed, and integrated. To perform this characterization, Texaco used depositional theory, well logs, fluid chemistry analyses, paleontology, pressure tests, production performance data, rock analyses from cuttings, cores, and sidewall cores, and computer reservoir simulations. The overall effort to date and the plans for future work are categorized by method of investigation and summarized in Table II.4.

By integrating depositional theory, paleontological data, and log characteristics (using log character, sand patterns, and faunal distribution), Texaco confirmed that the Marginulina Sand in the project area is an FDD reservoir (see Appendix D). As part of the reservoir characterization effort, Texaco initiated a new geologic field study in April, 1991. Existing Port Neches Field, Marginulina reservoir structure maps were reviewed; and paleontological data were evaluated. Electric logs were used to identify and characterize sand bodies. New maps and cross-sections were created from reexamined data (including structure and net oil isopach maps) and closely monitored. This examination also helped us to identify locations for future infill wells.

II.C.2. Accomplishments to Date

Well logs and existing seismic interpretations have been employed to generate a structure map, locate the faults, and determine the boundaries of the reservoir. Texaco plotted the results of bottomhole pressure tests for all fault blocks in the field and confirmed that the project area is actually two separate fault blocks.

Through the analysis of log and core studies, many reservoir parameters were determined. For example:

- Sidewall cores were gathered, and average permeability and porosity values were estimated for the field (750 md and 30%, respectively).

- Using structure maps and net oil isopachs derived from log data, the reservoir volume was calculated. Average permeability, porosity, oil/water/gas saturations, and reserve estimates were determined.

- Pressure buildup tests were run in many of the wells to determine near borehole permeability and skin factors.

Reservoir fluids were analyzed and the results of the analysis showed that the API gravity of the reservoir crude, a light oil, is currently 36.9° API, initial gravity was 38° API. Reservoir crude viscosity has increased from 0.97 centipoise initially, to its current levels of 2.4 centipoise, as a result of the liberation of free gas during the primary production phase. Waterflooding has also stripped away many of the light ends of the reservoir crude.

Additional fluid analyses have been performed to permit planning and design of the project, as well as to simulate the response of the reservoir fluids to the miscible CO2 flooding process. These characterizations included the following:

- Using the slimtube test, the minimum miscibility pressure for the reservoir crude was determined to be 3310 psia.
- An optimum vaporization test yielded an optimum vaporization pressure of 2740 psia at a reservoir temperature of 165°F.
- Constant composition expansion tests on stock tank oil were run to determine phase behavior of the reservoir crude with CO2

- Swelling/solubility and viscosity reduction experiments with CO2 on the stock tank oil were also conducted.
- Using live oil, the equation of state for the original reservoir crude was determined.
- CO2 flooding literature for FDD reservoirs was reviewed.

Extensive reservoir simulation and modeling work has been performed. Production and injection data from 1934 were gathered and analyzed for all wells in the area. Scientific Software-Intercomp's COMPIII and Simbest models were purchased, as was an IBM RISC 6000 workstation (installed in the Harvey, Louisiana office). Historical bottomhole pressures were plotted. Material balance analyses were performed with an in-house computer model, and the OOIP and aquifer influx constants were determined. A modified version of DOE's C02PM program for predicting CO2 oil recoveries in a five-spot flooded pattern was run. Also, Texaco personnel have analyzed production sensitivities to oil saturation, WAG ratios, and Dykstra-Parsons coefficients and have developed a dimensionless oil recovery curve. An oil production and CO2 production schedule for the flood was made using the generated C02PM dimensionless curve; however, we also determined that a need existed for a more comprehensive simulation model.

C02PM input/output results were applied to COMPIII, a compositional reservoir simulation model. Only the water-flood portion of the Marginulina reservoir was run. We entered 57 years of data on production, history, average permeability, and average porosity into the COMPIII model, and developed a relative permeability curve. The COMPIII model produced a match on total oil recovered from the project area, which allowed us to obtain an average current oil saturation. The production forecasts for oil and CO2 were compared to C02PM estimates, and the predicted oil forecast was adjusted.

The C02PM results were used to estimate injection and production volumes for the project area. Next the COMPIII results were used to develop CO2 project injection, production and recycle volumes. Texaco used the COMPIII model and the C02PM models to compare the suppliers of

CO_2 with the necessary volumes of CO_2 that are available and could be delivered to the Port Neches Field. In the future, Texaco plans to refine the COMPIII model to provide a more rigorous geologic description and fluid characterization. These enhancements will enable further project design optimization. Documentation of the reservoir characterization efforts that have been performed to date are included in Appendices D and E.

Texaco plans to drill three new wells in the proposed project area. Knowledge of depositional theory was used to optimize the location of these infill wells. Complete suites of logs will be run, including Dual Induction Focused, Formation Compensated Density, Compensated Neutron, Dipmeter, Gamma Ray, and SP logs. Sidewall cores will be taken from the objective sand in the new wells. Special core analyses will be run on conventional core by Texaco's Research Center. Relative permeability, residual oil saturation, and current saturation will be determined. Rock properties and geologic data which are useful in characterizing the reservoir will continue to be assessed and modified where necessary.

Texaco plans on running extensive logging and tracer programs to analyze the effects of heterogeneity in these reservoirs. Production response will be monitored. Progress of fluids through the heterogeneous reservoir will be observed by Pulsed Neutron Logs in producing wells. Radioactive tracers will also be used to monitor flow paths developed within the reservoir.

As a result of this continued data gathering effort, structure maps will be updated with additional data from new wells. Periodic CO_2 - oil bank maps will be drawn to show the movement/displacement of oil within the reservoir. This will aid in the identification of possible unswept reservoir compartments through the integration of depositional theory with hard data on fluid movement. The projected recoverable oil/water/CO_2 will be compared with the actual recovery and adjustments to the original forecast will be made where necessary.

Reservoir fluids will continue to be analyzed. Texaco will monitor compositional changes of the produced fluids. Produced fluid samples will be analyzed to detect changes in the oil (vaporization), water (to detect wellbore communication between reservoirs, if any, and to monitor corrosion through iron concentrations) and gas produced (to monitor the mixture composition to maintain miscibility).

The reservoir simulation model will be improved by the incorporation of permeability and porosity variations. Production will be monitored with the simulator to verify reservoir properties, and adjustments to the relative permeability curve will be made as necessary.

II.C.3. Current Status of Recovery Technology and Accomplishments to Date

Texaco has previously done CO2 floods in FDD reservoirs. The projects are summarized in Table II.5. From these results Texaco has determined that CO2 floods can be performed in FDD reservoirs. A critical difference between the former work and the proposed project is that former projects were in reservoirs that had not undergone waterflood before CO2 flooding. Texaco proposes to investigate the incremental recovery potential from an FDD reservoir with no aquifer, that has undergone waterflooding. The recovery in a waterflooded fault block will be compared with the results obtained in a smaller, partial waterdrive, fault block. This data will serve useful in developing a correlation based upon drive mechanisms.

Other significant differences between the former work and the proposed study exist. In the previous study areas, the depleted reservoir pressure was not increased to the miscibility pressure of *CO2* This project will be pressured with water in the waterflooded fault block, and with CO2 in the partial waterdrive faultblock. A comparison of production performance can be obtained by the utilization of these two processes. Water is used in the larger fault block because it has already undergone extensive waterflooding, and its reservoir boundaries are more well defined. The small fault block, on the other hand, has not been waterflooded, will not require as much CO2 to pressure the reservoir above MMP, and also has poorly defined fault boundaries due to the highly fluted nature of the piecement type salt dome. By pressuring the reservoir with CO_2, CO_2 can contact all regions of the fault block, irregardless of the configuration of the reservoir. Texaco's patented pull-pull process works well on small reservoirs. If the injection does not communicate with the producer, it can be produced at relatively good oil rates, thus avoiding total failure of the project.

A uniqueness to this project is also the horizontal well technology. Texaco recently completed the first horizontal water injector in the state of Texas in a mature waterflood. This well, drilled at the New Hope Field in Franklin County, Texas, was utilized to increase water injection into a relatively low permeability sandstone reservoir. The Port Neches Marginulina reservoir has relatively high permeabilities, however, Texaco realizes that the horizontal section of this well will penetrate some of the low permeability sections, thus improving sweep efficiency. An attached writeup by Texaco's research lab demonstrates the technical readiness of Texaco in this area of technology.

FDD reservoirs with aquifers are typified by low remaining oil saturations after primary recovery. FDD reservoirs with no aquifer have higher remaining oil saturations, even after waterflooding. Previous CO_2 projects in FDD reservoirs were performed in reservoirs with strong aquifers. These reservoirs have shown encouraging results, even though they have low remaining oil saturations after primary recovery. FDD reservoirs with weak or no aquifers that have undergone waterflood are a large resource target in which the process is untested. Texaco and other operators in Louisiana have waterflooded over 443 reservoirs, most of which are fluvial dominated deltaic reservoirs. Given the fact that this is probably less than half of this type reservoir, a large resource exists which needs to be explored. Original oil-in-place for these 443 reservoirs total 4.339 billion barrels, with 2.069 billion estimated as an ultimate recovery. An additional 20% recovery from these reservoirs by utilizing CO_2 techniques, would mean 868 million barrels of recoverable oil. Actual potential for these type reservoirs is probably closer to 2-3 billion barrels, as there are many depletion type reservoirs which have not yet been waterflooded, thus having even greater potential.

As a result of their investigations to date, Texaco developed the concept of Minimum Displaceable Oil Saturation (MDOS). MDOS is a new concept in screening reservoirs for CO2 flooding. MDOS is the minimum oil saturation that must exist in the pore space in order to successfully form an oil bank economically in a miscible CO2 flood. Presence of this minimum displaceable oil saturation, which is often felt to be 10% above residual oil saturation, is the most important criteria for the formation of an oil bank. Oil banking, which occurs in depletion drive and partial water drive reservoirs, is the most efficient process in miscible flooding. A miscible flood oil bank displaces all the moveable oil and a significant portion of the residual oil to waterflooding as it moves from the injectors to the producing wells. When a dense miscible fluid, such as CO2, is injected into an oil reservoir it will immediately vaporize some of the oil into the CO2 phase. In order to form an oil bank economically MDOS must exist in the reservoir. The Port Neches Field has a residual (immobile) oil saturation estimated to be 20% based upon log and core analyses, which is 12% below the current average oil saturation. This indicates that MDOS is achieved in this reservoir due to its current saturation greater than 10% above residual. MDOS, however, was derived from field data using a limited number of data points. This screening tool needs to be refined and corroborated by further CO2 flood data. The proposed project will supply additional needed data. The resulting refined product is a transferrable technological advancement.

Table II.5
Previous Investigations Compared to Proposed Project Examples

of Texaco FDD Reservoir Miscible CO2 Flood Projects

FDD Reservoir, No waterflood, strong water drive	FDD Reservoir, No waterflood, weak or no aquifer	FDD Reservoir, Waterflood, no aquifer (no waterdrive)
Bay Ste. Baine, BSE 8000' RE SU	Paradis, 9500',RC-7 SU	Project Area
Paradis, Lower 9000'RM SU	Paradis, Lower 9000'RA SU	
Paradis, No. 8 RA SU	Paradis, 16 Sand	

Documentation of the assessment of the Recovery Technology to date are included in Appendix C.

II.C.4. Readiness For Demonstration

Port Neches Field's Marginulina Sand is an FDD reservoir which have been water-flooded. The sand is compartmentalized in a manner consistent within the permeability and porosity variations expected in a FDD reservoir. The oil gravity is 36.9° API. The project area is under lease to and operation of a single entity, Texaco Exploration & Production, Inc.

Port Neches Field's Marginulina Sand is a solution gas drive reservoir with a weak aquifer, which has been water-flooded in one fault block and has not in another. Reservoirs with weak aquifers leave behind large quantities of residual oil. Also, FDD reservoirs, because of their facies variations and compartmentalization, have areas which remain virtually unswept. Reservoir characterization studies will be used to identify areas of high remaining oil saturation.

Original reservoir pressure was 2700 psia and depleted to 100 psia in the waterflooded fault block of the Marginulina reservoir. Current reservoir pressure is 1850 psia during water-flood operations. CO2 minimum miscibility pressure has been determined for the reservoir at 3310 psia (See Appendix C). Reservoir pressure will be raised to this minimum miscibility pressure by injecting salt water. The facilities and process have been designed. Preliminary infill drilling will increase access to reservoir compartments. Sites have been selected for the additional 3 wells to be drilled, including a horizontal CO2 injection well. Twelve wells will be worked over. New CO2 injection wells will be drilled at the original oil-water contact to ensure maximum sweep of the entire field. Injection and withdrawal of fluids will be closely monitored and controlled.

Miscible CO2 flooding of a previously post-waterflood FDD reservoir in the absence of a strong waterdrive is a novel application of a traditional technology. The project will be used to demonstrate that where remaining oil saturation is high due to the characteristics of the reservoir, even after waterflood, significant increases in the ultimate recovery from FDD reservoirs with weak or no aquifer (no waterdrive), can be accomplished by controlled injection of CO2 at miscible pressure.

The team has made major commitments to this technology to date. CO2 floods have been operated by Texaco in the past. Extensive design and planning tasks for this project have been completed. These include development of new screening criteria for CO2 floods and the development of the minimum displaceable oil saturation concept. (The traditional screening parameters are displayed in the accompanying Table II.7) Evaluations of the sources of injectant and comparative studies of the relative effectiveness of similar technologies have also been completed. Process chemistry and its interaction with the Port Neches Marginulina sand reservoir has been evaluated. No pilot scale field tests or prior demonstrations have been made in depletion drive, post-waterflood FDD reservoirs.

Table II.6

Criteria for the Application of CO2 Miscible Flood

Screening Parameters	CO2 Miscible	Port Neches Field, Marginulina Formation
Viscosity, cp at reservoir conditions	<12	.97 orig. 2.4 stock tank 0.513 at 70% Cp
Gravity, (2° API California crudes)	>30 (>28)	36.9
Fraction of oil remaining in area to be flooded (before EOR), % Pore Volume	25	32% - waterflood area 42% - partial waterdrive fault block
Depth, ft	> 3,000	6,000
Original bottomhole pressure, psi	> 1,500	2,700
Net pay thickness, ft	>10	33
Permeability, md	NC	750
Transmissibility (permeability x thickness/viscosity)	>20	48with 70% CO2

Texaco, a major operator, is extremely well qualified by experience and resources to undertake this project. Our industry-wide technical reputation will aid in the technology transfer. Project design is complete and Texaco is eager to begin in the implementation phase of the project. Texaco's management is backing this project and this technology as seen by our decision to staff the CO2 group with 23 individuals.

II.C.5. Identification of Technical Risks and Mitigation Methods

The technical risks that could affect the success of the demonstration have been identified, and measures to mitigate these risks have been planned. The risks are minor in comparison with other Gulf Coast operations; they include process uncertainties and reservoir unpredictability, which are described below.

The risk of poor CO2 sweep efficiency has been considered. To overcome sweep efficiency problems related to major reservoir heterogeneities, Texaco had made plans for infill injection wells to enable line drive flooding. This will be accomplished by one horizontal injection well, allowing for the contact of the entire residual oil column. We could also incorporate a Push-Pull component into the recovery plan if a problem (premature CO2 breakthrough) develops. Push-Pull is a Texaco-patented process that involves injecting of CO2 into all wells simultaneously (with no concurrent production). This forces CO2 into all areas of the reservoir and overcomes many heterogeneities.

Possible leakage of CO2 out of the reservoir is not anticipated. Reservoir pressure history has already proven that the reservoir is sealed. Therefore, we know that the CO2 will be contained within this reservoir. Reservoir pressure in this reservoir declined to 100 psia and has since increased to 1850 psia with water injection. The increased pressure is still well below original reservoir pressure of 2,700 psia. The risk of leakage is very small; but if occurs it would require that we purchase additional volumes of CO2. As in any well operation, safety is a concern. Because pressures will be elevated, safety control equipment will be installed to guard against uncontrolled flow of fluids and spills in the event of equipment failure.

II.D. RELEVANCE OF THE DEMONSTRATION

The proposed demonstration project, a miscible CO2 flood of the Marginulina Sand in Port Neches Field, will test the applicability of using a technology in an (FDD) reservoir, which has displayed promising results in other types of reservoirs. This CO2 flood will be applied to a post-waterflood fault block of the Marginulina reservoir, and in the same 5 year period, be tested in a partial waterdrive fault block of the same reservoir. This test process will aide the oil industry in evaluating the miscible CO2 flooding process in reservoirs which have undergone different drive mechanisms. Though CO2 has proven successful in removing additional oil from reservoirs, the oil industry must have a better idea of the incremental amounts which can be produced from various types of reservoirs, as well as, the time frame (i.e. production schedule) at which these reserves can be expected. The Port Neches Field project will provide all of these answers, so that the oil industry will have greater confidence in applying this technology.

The demonstration project will combine geological characterization of the reservoir with the application of two advanced oil recovery methods - miscible CO2 flooding and horizontal drilling - in a highly heterogeneous FDD reservoir that is currently producing light oil under secondary recovery operations. This proposed technology is expected to be successful in recovering a significant amount of incremental oil from an FDD reservoir that has a weak primary drive mechanism and a high remaining oil saturation. Results from the demonstration project are expected to be significant and will validate the appropriateness of using miscible CO2 flooding technology, coupled with horizontal drillings, in other FDD reservoirs.

II.D.1. Relevance of the Technical Demonstration

The results of the demonstration project are expected to validate the use of a miscible CO2 flood in other FDD reservoirs, particularly those reservoirs that have previously been water-flooded or that currently have a weak waterdrive, and provide a basis on which the decision to use the process in similar reservoirs can be made by the sector. Other petroleum operators will be able to predict the amount of incremental oil recovery that can be expected based on the experiences and results gained from this project. The impact of reservoir heterogeneities and the importance of characterizating of the reservoir will be demonstrated. The applicability of the technology to highly heterogeneous clastic reservoirs other than FDD reservoirs can be estimated from the relative degree of success of the project. The performance of a CO2 injection well can be evaluated, noting the improvements in sweep efficiency of the residual oil column.

II.D.2. Expected Applicability of Technology Being Demonstrated

The proposed technology - using miscible CO2 to recover bypassed and immobile oil that remains after conventional water-flood operations - is expected to be successful in most, if not all, FDD reservoirs. By their nature, these reservoirs are composed of rock compartments, or facies, that which exhibit great deal of variation in porosity and permeability. These facies are the products of the various depositional environments that occur within the general framework of the delta. Although the size and distribution of various depositional facies may not be the same between different fluvial dominated delta despositions, the same types of facies are common to most FDD reservoirs because the same types of depositional processes operate in all fluvial dominated deltas. The bypassed oil in these reservoirs is located in facies, that have relatively low permeability and that frequently are in contact with fades having higher permeability.

The Port Neches Field has a permeability variation common to most FDD reservoirs. High permeability exists in the lower portions of the sand, thus acting as high perm flow channels to injected water. With the density of water being high, the water tends to remain at the base of the sand due to gravitational forces. On the other hand, in CO2 flooding, this permeability variation is advantageous to additional recoveries due to the density difference between CO2 and the reservoir fluids. The CO2 will seek out the top part of the sands, contacting low permeability areas of these fining upward sequence sandstone reservoirs, and sweep out additional oil.

For the CO2 miscible flood technology to be successful, there must be a multitude of small facies with relatively high remaining oil saturation in contact with higher permeability channels. These areas of varying residual oil saturations are generally the result of differences in permeability throughout the reservoirs, and poor sweep efficiencies found in post-waterflood FDD reservoirs. Although the highly permeable zones will receive a greater percentage of the CO2 injectant, they will allow the flood to quickly contact areas of lower permeability that are further away from the injection wellbore. FDD reservoirs contain these highly permeable zones, particularly channel deposits and distributary mouth bar sands, that they facilitate the flow of injectant through the reservoir, avoiding contact with the areas of high remaining oil saturation. CO2 removes all fluids it comes in contact with, thus opening up flowpaths to unswept regions of the reservoir. Therefore, it is expected that the CO2 miscible flood would be successful in a large percentage of FDD reservoirs.

II.D.2.1. ***Encouraging Private Sector Implementation***

The results of the proposed technology in the Port Neches field will enable other oil and gas companies to assess the practicability and appropriateness of using this technology in other reservoirs of this category. This technology is expected to have widespread applicability among other FDD reservoirs because it is common for these reservoirs to have relatively weak primary drive mechanisms and high remaining oil saturations after secondary recovery techniques, such as waterflooding, have been applied. Factors that could affect a company's decision to use this technology may include:

1) The incremental oil recovery expected by applying this process.
2) The availability and cost of CO2, including transportation costs.
3) The costs of facilities, well workovers, drilling additional injection and/or producing wells, and incremental operating costs associated with the project.
4) The CO2 recycle compression cost.
5) The overall project economics.

Based on the degree of success and profitability of the proposed project, other petroleum operators that have similar reservoirs will be able to make intelligent decisions concerning the merit of using the proposed technology.

Texaco will promote the use of this technology to other petroleum operators, particularly independent oil companies. This technology is expected to be suitable for small fields that contain only a few number of wells, and for larger fields that have many wells. For that reason, this process will be especially attractive to independent oil operators that possess small fields. One injector and one producer may be sufficient enough in small fault blocks, to utilize the push-pull technology developed by Texaco. Our application for this type flood in the small fault block at Port Neches will provide many answers. Based on the degree of success of this proposed technology demonstrated by Texaco, other oil operators will have the necessary information available to make proper decisions concerning the application of the miscible CO2 flood process to their reservoirs.

II.D.2.2 ***Impact of Reservoir Heterogeneities***

Reservoir heterogeneity can be described as the degree to which fluid-flow is affected by variations in permeability between the various lithologic units, or fades, that comprise a particular reservoir. In a perfectly uniform, isotropic reservoir, the resistance to fluid flow is equal in the X, Y, and Z directions. This situation is rarely encountered in natural reservoirs because they are composed of various facies that each have highly variable fluid-flow characteristics. For example, a sand body that was formed as a beach deposit can be expected to have little of heterogeneity because the size and shape of the sand grains are relatively uniform and because the depositional processes that formed the deposit were probably fairly uniform over a wide area. In contrast, the depositional processes and resultant facies that are common to fluvial dominated deltas exhibit a greater degree of variability over much smaller areas. It is this variability in reservoir quality, or heterogeneity, that results in uneven drainage of oil from the reservoir and causes oil to be bypassed by conventional secondary recovery techniques.

FDD, are characterized by high sediment influx, relative to wave and tidal energy flux, which reworks sands and silts after transport and deposition. This dominance of sediment supply over wave and tidal energy results in sand being deposited in elongated channels on the upper delta plain and in wedge-shaped bar sands at the mouths of distributary channels in which current energy dissipates. These relatively clean sands are deposited adjacent to silts and clays, which in turn, are deposited in areas of low energy relative to the main river and distributary channels. The juxtaposition of high and low energy environments and their correlative facies forms a volume of sediments in which clean sand bodies are enveloped in fine-grained silt and mud deposits. The reservoir that forms during lithification of the sediments retains the same character, so that highly porous and permeable sand units are encased in tight clays and shales. It is this resultant highly heterogeneous reservoir that provides an ideal environment for the CO2 miscible flood technology being proposed.

Miscible CO2 flooding has been successfully demonstrated in pressure-depleted reservoirs in South Louisiana (Bou-Mikael and Palmer, 1989). Bypassed oil is liberated by the applying miscible CO2, in a combination of two processes: vaporization and oil banking. Vaporization is the process by which miscible CO2 extracts the various hydrocarbon components within the oil by effectively lowering the viscosity of the oil and forming a miscible fluid that contains both oil and *CO2.* Oil banking is the process by which a miscible oil-CO2, fluid that was formed by vaporizing a portion of the oil in a reservoir, moves through the reservoir and displaces both mobile and immobile oil. It has been observed that vaporization is more important in strong waterdrive reservoirs and that, oil banking is more prevalent in weak waterdrive and solution gas drive reservoirs. Bou-Mikael and Palmer (1989) postulated that, to successfully form an oil bank, a Minimum Displaceable Oil Saturation (MDOS) must exist in the reservoir. MDOS is defined as "the minimum oil saturation that must exist in the reservoir pore spaces to successfully form an oil bank economically in a miscible flood." The relative success of forming an oil bank in a miscible flood is mostly dependant upon the remaining oil saturation in the reservoir. Of the two processes, oil banking is more efficient in recovering the additional oil that remains after waterflood operations. Vaporization requires large volumes of CO2 to be injected in comparison with the volume of incremental oil recovered. Oil banking is much more efficient in recovering mobile and immobile oil, particularly in solution gas drive and weak waterdrive reservoirs.

In this demonstration, Texaco hopes to prove that the more efficient oil banking process can be performed in a post-waterflood FDD reservoir. Due to its reservoir heterogeneity, this has yet to be attempted. It is known that, in FDD reservoirs with strong aquifers and resulting low remaining oil saturations, vaporization occurs and recovery has poor to fair results. It is also known that FDD reservoirs, with weak or no aquifers, have high remaining oil saturations after primary recovery and that oil banking resulting from the miscibility process yields good results. This process will be confirmed in the small fault block. An investigation of the success of this process in FDD reservoirs, with weak aquifers that have undergone waterflood, will be examined in the large fault block.

II.D.2.3. Expected Incremental Production From Widespread Application

Petroleum Information, Inc. estimates that the original oil-in-place (OOIP) for this Gulf Coast trend is about 25 billion barrels. Texaco estimates that approximately half of these FDD reservoirs. Widespread application of the proposed miscible CO2 technology to other suitable FDD reservoirs is conservatively expected to yield an incremental 2.5 billion barrels, or 20% of this 12.5 billion barrels, in place for FDD type reservoirs. This figure is based on the assumption that about 50% of the FDD reservoirs in the Southern Louisiana-Texas coastal area have relatively weak primary drive mechanisms which usually result in two-thirds of the OOIP not being swept after primary operations. Information developed from a 1979 report from the State of Louisiana entitled, "Secondary Recovery and Pressure Maintenance Operations in Louisiana," indicates that 443 waterfloods had been conducted in Louisiana up until that time. These reservoirs had an estimated original oil-in-place of 4.339 billion barrels, and an ultimate primary and secondary recovery of 2.069 billion barrels, or 47.7% OOIP. Texaco believes that approximately half of these remaining reserves, or 1.135 billion barrels can be recovered by CO2 flooding technology. From Texaco's experience, these 443 reservoirs represent only a small portion of the pressure depleted reservoirs in Louisiana. Stating that 2.5 billion barrels of additional oil is recoverable by applying this CO2 miscible, flooding and horizontal drilling technology, may be conservative.

In the Port Neches Field, Texaco has estimated that of the remaining 4.9 million bbis which remain after waterflood, an additional 2.2 million bbls or (19% OOIP), will be recovered after applying of the proposed miscible CO2 flooding technology. The incremental oil recovered by this process will be derived from both unswept and swept zones within the reservoir. In FDD reservoirs that have weak primary drive mechanisms, (e.g. the Port Neches field), the remaining oil saturations after secondary recovery operations are typically about 20% in swept zones between between and 20% and 80% in unswept zones. It is estimated that, after applying the proposed miscible CO2 technology, the remaining oil saturation in swept zones would be in the range of 5 to 10%, yielding an incremental recovery of 10 to 15% of OOIP from the swept zones. In the less permeable, unswept zones, it is estimated that the remaining oil saturation after applying miscible CO2 flooding would be in the range of 10 to 30%, yielding an incremental recovery of 10 to 50% of OOIP from the unswept zones. The amount of incremental oil recovered from a particular FDD reservoir will be a function of the remaining oil in the swept and unswept zones which. The amount of remaining oil is dependent upon the strength of the primary drive mechanism. Applying of the proposed miscible CO2 flooding technology, to other suitable FDD reservoirs which have been waterflooded, should recover incremental reserves similar to the 19% of OOIP estimated to be recoverable from the Port Neches Field. For those reservoirs which have not been waterflooded, the recovery may be as high as 30-35% OOIP.

II.D.2.4. Applicability of Process to Other Reservoir Types

The proposed miscible CO2 technology would probably be applicable to the reservoir types other than FDD reservoirs which exhibit a similar degree of heterogeneity. This technology may be applicable to clastic reservoirs that have of heterogeneity similiar to FDD reservoirs. Some examples would include fluvial reservoirs and slope-basin turbidity reservoirs. Each of these depositional types contains channel deposits of highly permeable sands that are in contact with finer-grained, lower-permeability levee or slope deposits. As is true with FDD reservoirs, the areas of higher remaining oil saturation would be the less permeable depositional facies that would be contacted by the injectant via the more permeable channel deposits. The proposed technology is expected to be more suited for highly heterogeneous reservoirs with relatively higher remaining oil saturations, than for more homogeneous reservoirs which have lower remaining oil saturations because homogneous reservoirs generally have more efficient recovery of oil during primary and secondary recovery operations. Fluvial channel deposits and slop-basin turbidity deposits are two possible candidate reservoir types for which the proposed miscible CCL flood technology may be applicable. If these reservoirs have not been waterflooded, a homogeneous reservoir will be very conducive for CO2 injection.

II.D.2.5. *Expected Incremental Production From Application on Other Reservoir Types*

Application of the proposed miscible CO2 flood technology to reservoirs other than FDD reservoirs) that have similar heterogeneity is expected to yield similar percentages of incremental oil recovery. In terms of remaining oil-in-place, slope-base reservoirs such as turbidities, rank second to FDD reservoirs. According to the DOE Oil Research Implementation Plan, approximately 22 billion barrels of oil remain in Slope-basin reservoirs. Of this amount a significant percentage will remain unrecovered after secondary recovery operations are completed. The remaining oil represents a sizeable energy resource that may be recovered the application of the proposed miscible CO2 flooding technology. The use of the miscible CO2 flooding technology would be most appropriate in slope-basin reservoirs that have weak primary drive mechanisms and resultant high remaining oil saturations.

Although not as large a potential resource recovery target as slope-basin reservoirs, fluvial reservoirs still contain 4.5 billion bbls of oil as a target for applying the miscible CO2 flooding process. Assuming that the recovery efficiencies using the proposed process for these other reservoir types is similar to the recovery efficiencies of FDD reservoirs, incremental oil recovery would be about 20% of OOIP, which is significant amount of oil. Even at lower recovery efficiencies, the proposed technology could yield sizable amounts of incremental oil because of the large amount of unrecovered oil contained in slope-basin and fluvial reservoirs. An incremental oil recovery of 2.5 billion barrels, equipment to that obtainable in FDD reservoirs, is felt to be a real possibility if oil prices stabilize, and industry confidence in the CO2 process grows.

II.D.3. Site Suitability

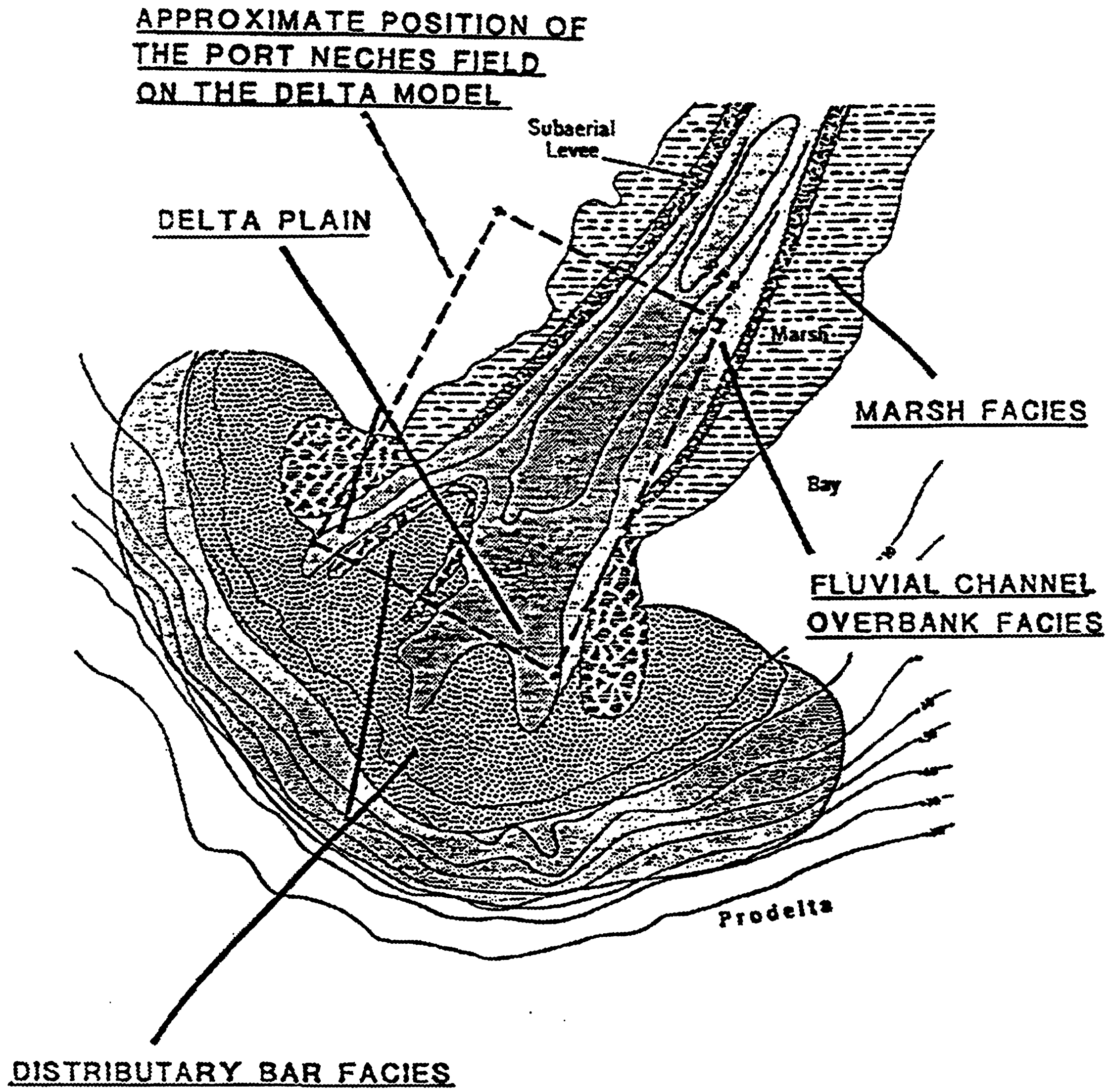
II.D.3.1. Site Production Validation

The proposed demonstration reservoir, the Marginulina Sand in Port Neches field, is qualified for consideration under this program because it currently produces light oil (>20° API) and has been characterized geologically as an FDD reservoir. The gravity of the oil has been measured and certified as being in the range of 34 to 38° API by the Texas Railroad Commission. A copy of this certification is included in Appendix D.

II.D.3.2. Site Geologic Validation

The Port Neches field Marginulina Sand has been identified as an FDD reservoir on the basis of a geological report prepared by Alexander Enterprises, Inc. (Appendix B). The geological study of this reservoir included an assessment of paleontologic data and well log data, which were used to determine the depositional environment of the Marginulina Sand (Figure II.11). This is the equivalent reservoir to the Marginulina Vag. of the Sunshines field, a TORIS - listed FDD reservoir. The authors of this report concluded that the Marginulina Sand in the Port Neches field was deposited in an FDD environment. They reached this conclusion based on the evidence that facies present in the reservoir were indicative of this environment, particularly the distributary mouth bar and delta plain sands.

TYPICAL FLUVIAL DOMINATED DELTAIC DEPOSITS



DELTA FRONT SUBENVIRONMENTS AT THE MOUTH OF SOUTHWEST PASS, MISSISSIPPI RIVER DELTA. COLEMAN AND GAGLIANO, 1965

TEXACO E&P INC.

Figure II.11 Location of Field in Deposystem
PORT NECHES FIELD
ORANGE COUNTY, TX

II.E. TECHNICAL AND PROJECT MANAGEMENT APPROACH

Texaco's technical and project management approach is driven by the fact that we have for many years maintained a strong position with reserves in FDD reservoirs we in early 1990 began serious efforts to develop profitable methods to produce the remaining oil in the Port Neches field using CO2 flooding technology. We have been researching the applicability of CO2 flooding in FDD reservoirs for over 20 years. We formed the CO2 Projects group under CO2 Area Manager in early 1991 with the objective of profitably producing the remaining oil in FDD reservoirs such as Port Neches. Because of this experience, Texaco believes that it is the leader in CO2 flooding technology. The CO2 Projects group is part of the Onshore Producing Division of Texaco Exploration and Production, Inc., which effectively makes the entire management infrastructure, technical capability and financial resources of Texaco, available to support the Port Neches project.

As a result of its initiatives in this area, Texaco has already completed almost all of the reservoir characterization work at Port Neches. Therefore, we strongly believe that we are providing DOE with a viable project that will demonstrate the producibility of FDD reservoirs using CO2 flooding technology. By the time of selection, we expect to have the reservoir characterization and the engineering design work fully completed. A detailed description of the current status of this work has been provided in Sections II.B and II.C.

Texaco uses a matrixed technical and administrative support resources in a "business as usual" manner but supplemented by modifications to our normal practices that incorporate additional DOE business management requirements. We have selected Science Applications International Corporation (SAIC) as our management support contractor because of its experience in coordinating and managing government/industry cost-shared field projects. Because of the advance stage of development of our CO2 flooding technology, the readiness and applicability of the Port Neches Field, the experience and technical expertise of our project team, and the commitment of our full support infrastructure, Texaco believes that it is providing the strongest possible technical and project management capabilities to DOE for the Port Neches Project.

II.E.1. Technical Approach

II.E.1.1. Overview of Proposed Technical Approach

The technical approach for the proposed Port Neches project is based on the successful execution of several interrelated activities, all of which will be performed with the objective of producing additional movable and residual oil that cannot currently be produced economically using conventional methods. We currently estimate that there are approximately 5.1 million barrels of oil remaining in the Port Neches field's project area, and that at least an additional 2.2 million barrels can be produced using the miscible CO2 flooding process. The elements of our technical approach described below are intended to achieve this objective.

First, a thorough and accurate reservoir characterization must be performed. Te xaco has almost completed an extensive characterization of this field, which includes gathering and analyzing 57 years of production data, generating new top of sand maps, determining porosity and permeability values for the sand, and generating a depositional theory report of the FDD nature of the reservoir. We have also run extensive reservoir simulation using this data to develop what we believe is an accurate picture of the remaining oil saturation throughout the reservoir. Areas of low permeability, layering of the sand, faulting, the heterogeneity barriers and other depositional characteristics are identified. The recovery

system and process designs have been completed, including the utilization of a horizontal injection well. See Section II.B and II.C for a detailed description of the reservoir characterization.

Next, Texaco developed accurate projections of the horizontal and vertical sweep efficiency of the miscible CO2 flooding process. For the process to be economically viable, oil banking must occur. Texaco has performed extensive laboratory and field tests over the past 20 years to develop a fundamental understanding of the mechanisms of CO2/oil interactions that result in efficient oil banking. Our studies indicate that the Port Neches field is an ideal candidate for the miscible CO2 flooding process.

Recovery system design is a vital component of our technical approach. The process will be used to achieve good vertical and horizontal sweep efficiency. Drilling of a horizontal well along the boundary of the original oil/water contact, will allow injection to be done uniformly along this residual oil interface. See Figures 11.3 and 11.4 for the locations of the injection and production wells.

Process design is the next step in our approach. The process must efficiently recover the oil, but at the same time, must apply techniques which can optimize the economies of the project. We will drill infill CO2 injection wells to increase access to previously bypassed oil, pressurize the reservoir with saltwater before injecting CO2, and recycle all produced CO2 to minimize purchases.

Finally, we will emphasize safety and environment protection, by installing new corrosion protected equipment. A large cost for the project will be well workovers, which are required due to the corrosive nature of CO2. Wells will be equipped with stainless steel screen and liners to protect against sand production from the unconsolidated sand reservoir. We will place special emphasis on innovative and cost-effective methods for accomplishing these workovers, to insure reduced project costs, and at the same time, will increase their chances of success.

II.E.1.2. Use of Reservoir Data

Available reservoir data have been extensively described in Section II.C. These data have been used to support our reservoir simulation studies and were used to develop the recovery system and process designs discussed in Section II.B.

II.E.1.3. Approach to Technology Transfer

Texaco believes that there is approximately between 2.5 billion barrels of recoverable oil in FDD reservoirs that may be recoverable with miscible CO2 flooding technology. This technology can also be applied to other reservoir types, where an additional 2.5 billion recoverable barrels is possible. Significant benefits to the oil industry and the nation will thus be achieved by a successful demonstration of the technical and economic feasibility of this technology at the Port

Neches field. We enthusiastically endorse DOE'S objective of transferring technology from this project to other reservoirs throughout the industry. Our specific proposal for technology transfer is described below.

We believe that our reservoir characterization methodology for this reservoir represents several advanced features that will be useful to other organizations and companies that the interested in developing FDD reservoirs. We will make a presentation on our project design and reservoir characterization techniques at the October, 1992 SPE National Convention if selected, and process design to the DOE during the 4th quarter, 1993. An additional SPE paper will be presented on reservoir characterization in the 4th quarter, 1994. This report will be disseminated both through SPE and through DOE's established technology transfer channels such as OSTI.

Next, we believe that we understand the process of miscible CO2 flooding and the geology of FDD reservoirs well enough that we can develop a screening procedure that will greatly assist an interested company in identifying potential CO2 candidates. In cooperation with Louisiana State University, the Toris database will be updated and expanded to allow for screening of all FDD reservoirs, and estimates will be made regarding the recoverable amount of oil obtainable by utilizing CO2 recovery methods. A topical report will be presented to the DOE during the 1st quarter of 1997 tabulating all of the findings of this study, with an estimate of CO2 recoverable reserves by reservoir. Texaco will hold industry forums prior to this time beginning in 1995, spreading the word of preliminary findings.

An SPE paper on final results of the Port Neches Field CO2 miscible flood will be presented during 1996. This paper will describe actual performance versus projected performance from the reservoir and necessary changes that were made. Reservoir modeling improvements and limitations will be discussed, along with key reservoir characterization findings for the project.

II.E.L4. Summary of Statement of Work

The first principal objective of the Port Neches Project is to determine the feasibility and producibility of CO; miscible flooding techniques enhanced with horizontal drilling applied to a

Neches field. We enthusiastically endorse DOE's objective of transferring technology from this project to other reservoirs throughout the industry. Our specific proposal for technology transfer is described below.

We believe that our reservoir characterization methodology for this reservoir represents several advanced features that will be useful to other organizations and companies that the interested in developing FDD reservoirs. We will make a presentation on our project design and reservoir characterization techniques at the October, 1992 SPE National Convention if selected, and process design to the DOE during the 4th quarter, 1993. An additional SPE paper will be presented on reservoir characterization in the 4th quarter, 1994. This report will be disseminated both through SPE and through DOE's established technology transfer channels such as OSTI.

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II.E.L4. Summary of Statement of Work

The first principal objective of the Port Neches Project is to determine the feasibility and

Fluvial Dominated Deltaic reservoir. The second principal objective of the Project is to disseminate the knowledge gained through established Technology Transfer mechanisms to support DOE's programmatic objectives of increasing domestic oil production and reducing abandonment of oil fields.

Texaco has acquired 100% of the rights to the Port Neches field and will provide the site for the Project. Texaco will provide the management, planning, reservoir characterization, recovery and production system design, engineering support, subsurface and surface facilities, equipment, $CO2$ and site operations necessary to develop and demonstrate producibility of the Port Neches field. A detailed proposed Statement of Work is contained in Appendix A to Volume II.

II.E.1.5. Proposed Work Breakdown Structure

The work breakdown structure for the project is illustrated in detail in the following Table.

II.E.1.6 Approach to Environmental Data Reporting

As indicated in the Work Breakdown Structure and Statement of Work, numerous permits will have to be obtained during design, construction, and operation of the project. Permits will have to be obtained from the Texas Air Quality Control Board, the Texas Railroad Commission, the Texas Board of Health, the Army Corps of Engineers, and the US Department of Transportation, among others. Once permits have been obtained, we will have to demonstrate compliance throughout the life of the project. These activities are things that Texaco normally has to do on any oil field development project, and we will perform them as a matter of course. Although DOE is responsible for NEPA compliance activities on the project, Texaco will be responsible for delivering environmental data packages to support DOE's work. In the course of obtaining the various permits from the various agencies, we will compile a comprehensive set of surface water quality, air quality, groundwater quality, waste streams, archaeological, and socioeconomic data. We will submit both the raw data packages and the permit applications to DOE for their use. If DOE needs this data compiled into a specific format to support development of a FONSI document, we will supply it on a schedule consistent with DOE's needs.

II.E.1.7. Conduct of Formal Project Reviews

Formal Project Reviews will be an important part of the project, both from the standpoint of Texaco exercise proper management oversight, and from the standpoint of keeping DOE informed and involving them in discussion of important issues. Two types of Formal Project Reviews will be held for the Port Neches Project. First, the Project Oversight Committee, discussed in II.E.2, will meet monthly to provide technical review and guidance. Second, we will hold Quarterly Project Reviews with DOE to present the status of all aspects of the project and discuss issues of mutual interest.

II.E.2. Project Organization, Capabilities, and Availability

Texaco will employ a project management approach that makes maximum use of our established engineering, production, and administrative support organizations. The Onshore Producing Division of Texaco Exploration & Production, Inc. has been operating profitably for many years and has extensive successful experience in developing and producing oil and gas fields, including FDD reservoirs. Texaco recognizes that the Port Neches Project, cost-shared with DOE, will have special project management, technology transfer, and reporting requirements that are in addition to our normal business management practices. To satisfy these requirements and to ensure that DOE receives the full measure of technology development and technology transfer for its investment in the project, we will supplement our normal business practices with whatever additional procedures and controls are required for this project. We have included SAIC as a team member to provide the additional management support necessary to meet all of DOE'S requirements. We are confident that this approach will result in a successful project.

II.E.2.1. Management Approach mid Organization

Texaco will perform the Port Neches project in the Onshore Producing Division of TEPI. The Port Neches project organizational structure will use Texaco's existing organization and business practices to the extent that it is consistent with the DOE requirements set forth in the Program Opportunity Notice. We have added a management support contractor to assist the Project Engineer with project tracking, reporting, special engineering problems, and financial and contract administration. Figures 11.12 and II.13 illustrate the organization of Texaco Onshore Producing Division, and CO2 Projects Group, respectively.

TEXACO WBS

NUMBER	TITLE	ACTIVITIES
01.01.00	**PHASE I - PLANNING AND ANALYSIS**	
01.01.01	Management and Administration	
01.01.01.01	Administration	• Identified Texaco fields along the Gulf Coast which have high remaining oil saturations and nearby CO_2 sources. • Developed business plan to incorporate CO_2 flooding technology and formed CO_2 design team in March, 1991. • Held periodic meetings with Texaco's Research Center in Houston to determine viability of CO_2 technology to fluvial dominated deltaic reservoirs along the Gulf Coast. • Appropraited funds in the capital and expense budgets to cover costs of pilot CO_2 injection programs. • Received management approval to purchase reservoir simulation computer hardware and software. • Obtained support from other entities within Texaco involving CO_2 source and pipeline applications. • Received management approval to have geological study of Port Neches Field performed. • Preliminary work on the unitization of the proposed CO_2 project has been performed. • To expedite unitization approval, the remaining working interest owner (16.67%) in the project area other than Texaco was bought out to give Texaco 100% working interest on all three leases.
01.01.01.02	Planning and Project Economic Analysis	• Identified geological depositional environment of Port Neches Field and determined reservoir characteristics most advantageous to enhanced oil recovery process. • Evaluated enhanced oil recovery processes for high API gravity fluids and determined that CO_2 is most cost effective means of extracting additional oil from the reservoir rock. • Performed economic evaluation of two potential CO_2 supplies in the Port Neches area. • Incorporated production and water injection data into geological model to determine recovery efficiencies. • Evaluated project costs for drilling, workovers, and facilities, and negotiated purchase price for CO_2 delivered to field. • Investigated CO_2 flooding technology process through comprehensive meetings with CO_2 suppliers, research personnel, and other Operators of CO_2 floods in the Gulf Coast region. (Held meeting with Shell Oil Company discussing Weeks Island CO_2 flood and George R. Brown discussing Rose City Field CO_2 flood). • Evaluated project economics and identified need for outside funds. • Reviewed outside sources of funds.
01.01.01.03	Deliverables/ Milestones	• Selected Port Neches Field, Marginulina sand as a promising opportunity. • Selected CO_2 as the tertiary recovery process. • Delivered geologic field study on depositional environment. • Delivered pre-project reservoir characterization work to management, including updated geological structure maps. • Developed cost estimates for the drilling of 3 wells (including 1 horizontal well), workover of 12 wells, and all necessary flowline, pipeline, tank battery, and compression requirements. • Presented project design and economics to Texaco management. • Decided to team with SAIC to pursue DOE as source of outside R&D funds. • Delivered DOE proposal.

NUMBER	TITLE	ACTIVITIES
01.01.02	Reservoir Characterization	
01.01.02.01	Field Testing & Field Evaluation	• Ran well pressure data and determined which fault blocks are connected. • Used existing electric logs to identify and characterize sand bodies. • Ran pressure buildup test and determined permeability and skin factors of reservoir, as well as, aquifer influx coefficients. • Collected representative fluid samples from producing wells in Marginulina reservoir to have PVT and slimtube laboratory work performed. • Reviewed existing Port Neches Field, Marginulina sand reservoir and structure maps. • Began new geologic field study in April, 1991. • Determined Marginulina sand was deposited in an FDD environment by log character, sand pattern and fauna. • Performed paleontological studies. Created new maps from reexamined data (structure and net oil isopach). • Performed volumetric calculations.
01.01.02.02	Lab Testing	• Analyzed sidewall cores and estimated permeability and porosity average values for the project area (750md and 30%). • Ran slimtube tests on the reservoir stock tank oil and live oil samples. Determined minimum miscibility to be 3310 psia at 165 . • Ran optimum vaporization test on reservoir crude and determined optimum vaporization pressure to be 2740 psia at reservoir temperature (165°F). • Ran constant composition expansion tests on stock tank oil and live oil samples to determine phase behavior of reservoir oil. • Ran CO_2 swelling tests and viscosity reduction tests on stock tank oil and live oil samples. • Utilized lab derived coorelations to develop relative permeability curve for reservoir rock.
01.01.02.03	Simulation & Computer Modeling for Reservoir Characterization	• Incorporated reservoir characterization data into simulator to obtain 31 year primary production history match and 26 year secondary waterflood production history match. • Adjusted relative permeability curve used in model to match actual production history of primary and secondary phases of production. • Analyzed sensitivity of reservoir characteristics to oil saturation, WAG ratios, and Dykstra-Parsons coefficients.

NUMBER	TITLE	ACTIVITIES
01.01.03	Extraction Technology Design and Engineering	
01.01.03.01	Model the Process	• Reviewed current tertiary work. • Reviewed CO_2 flood literature for FDD reservoirs. • Ran slimtube test on reservoir crude and determined minimum miscibility pressure (3310psia). • Ran swelling/solubility and viscosity reduction experiments with CO_2 on the stock tank oil. • Determined the equation of state for the original reservoir crude using live crude.
01.01.03.02	Simulation and Computer Modeling for Process Design	• Gathered and plotted production and injection data on all wells 1934 to present. • Plotted historical bottomhole pressures for all fault blocks. • Performed material balance analysis with in-house computer model. • Determined OOIP and aquifer influx constant. • Ran modified version of the DOE's CO2PM program for predicting CO_2 - oil recoveries in a 5 spot flooded pattern. • Analyzed production sensitivities to oil saturation, WAG ratios, and Dykstra-Parsons coefficients and developed a dimensionless oil recovery curve. • Forecasted an oil production and CO_2 production using the generated CO2PM dimensionless curve. • Determine need for a more comprehensive simulator. • Applied CO2PM input/results to COMPIII, a compositional reservoir simulation model. • With the COMPIII model, entered 57 years of production history, average permeability, and porosity data. • Developed a relative permeability curve. • COMPIII model matched total oil recovered from project area, thereby obtaining an average current oil saturation and saturation distribution. • Compared production forecast for oil and CO_2 to CO2PM estimates and adjusted predicted oil forecast. • The COMPIII model and the CO2PM models were utilized to compare suppliers of CO_2 with different available CO_2 volumes.
01.01.03.03	Design Field Implementation	• Identified fault block within the Port Neches Field for application. • Used the CO2PM results to estimate injection and production volumes of project area. • Used COMPIII results to develop CO_2 project injection, production and recycle volumes. • Identified CO_2 compression requirements. • Identified location for infill wells. • Designed drilling program, including horizontal well. • Designed workover program. • Designed surface facilities for CO_2 injection.

NUMBER	TITLE	ACTIVITIES
01.01.04	EHSS Planning	
01.01.04.01	Effluents, Wastes & Byproducts	• Reviewed current water production/discharge volumes and compared with CO_2 project requirement. • Estimated a reduction in surface water discharges as existing produced water is used to repressure reservoir, volumes will further decrease over time as a result of discontinuing water injection. • Identified solid wastes and effluents for drilling and workover program.
01.01.04.02	Greenhouse Gases & Air Toxics	• Identified anticipated increased emissions of NOx, VOC's. • Estimated a small increase in air emissions with installation of 2 compressors and 2 pumps. • Estimated additional VOC's via tank battery, fittings, and valves. • Identified permitting requirement needs for new battery location, new compressor siting, and for dehydrator. • Estimate CO_2 losses expected from routing aeration and "catastrophic" releases.
01.01.04.03	Compliance & Permitting	• Evaluated existing H&S training program. • Determined enhanced training needs related to handling: - high pressure gas/liquids - low temperature liquids - confined spaces/anoxia • Identified need for Corp of Engineers Permits for: - dredging canal - platforms construction - pipeline laying • Existing maintenance dredging permit to be utilized until December 31, 1992 then will be extended. • Develop Department of Transportation Manuals for affected lines. • Identified additional requirements for maintenance & surveillance documentation.
01.01.04.04	Socioeconomic	• Reviewed current status and future needs for Texas Parks & Wildlife involvement with: - wildlife management - saltwater intrusion (regional problem)

NUMBER	TITLE	ACTIVITIES
01.02.00	PHASE II - IMPLEMENTATION/DEMONSTRATION	
01.02.01	Management and Administration	
01.02.01.01	Administration	• Finalize DOE contract with Statement of Work. • Set up separate cost center for accounting. • Obtain unitization agreement with royalty owners and prepare Texas Railroad Commision hearing documents for project approval. • Acquire dredging and drilling permits for 3 new well locations. • Obtain water and CO_2 injection permits for 6 wells. Obtain flowline and injection permits on 15 wells. • Obtain Army Corps of Engineers approval for tank battery and compressor sites. • Obtain right of way permits for CO_2 gathering lines to and from onshore compressor site. • Prepare finalized Texaco form G-45 AFE for Texaco management approval. • Prepare Texas Railroad Commision form for State severance reduction from 4.6% to 2.3% for 10 year period. • Prepare Federal tax credit reduction form for 15% federal tax credit on capital investments on EOR project.
01.02.01.02	Project Economic Analysis	Prepare final economic analyses for Texaco form G-45 to fund capital and operating expenditures. Run sensitivity analyses to oil prices and production forecast.
01.02.01.03	Deliverables/Milestones	• Report daily oil, water and gas production for project area. Test individual production wells a minimum of once per month. • Report CO_2 injection volumes by well on a daily basis. • File monthly production and injection reports with Texas Railroad Commission. • Provide initial and quarterly Federal Assistance Milestone Plan. • Complete and submit Federal Assistance Budget Information. • Provide initial and quarterly Federal Assistance Management Summary Report. • Provide monthly Federal Assistance Program/Project Status report. • Provide monthly Financial Status Report, OMB Form 269. • Provide initial Notice of Energy RD&D. • Provide Quarterly Technical Progress Report. • Provide Topical Reports as determined in SOW. • Provide Final Technical Report.

NUMBER	TITLE	ACTIVITIES
01.02.02	Reservoir Characterization	
01.02.02.01	Field Testing & Field Evaluation	• Conventional rubber sleeve cores will be cut and analyzed on the Stark -B- No. 36 and J. V. Polk -B- No. 39. Drill cuttings will be characterized on the horizontal section of the Kuhn No. 54. • Dual Induction Focused Log, Formation Compensated Density Log, Compensated Neutron Log, Dipmeter, Gamma Ray, and SP will be run in openhole from TD to surface pipe. • Sidewall cores will also be shot to evaluate sand. • Run tracer surveys after adding radioactive markers to injectant, different markers in each injection well, and monitor the progress of movement of the fluids through the reservoir. • Use tracer survey information to interpret impact of reservoir heterogeneities. • Update structure maps and cross-sections with additional data from new infill wells. • Draw periodic CO_2 - oil bank maps showing the movement/displacement of oil within the reservoir. • Identify possible unswept reservoir compartments through depositional theory. • Compare projected recoverable oil/water/CO_2 with actual and make adjustments to theory where necessary.
01.02.02.02	Monitor and Evaluate	• Measure daily oil and water production from tank batteries and allocate to producing wells. • Measure surface pressure of producing and injection wells daily. • Measure CO_2 injection volumes to each well daily. • Measure CO_2 gas composition on a quarterly basis. • Measure API gravity on producing wells two times per year. • Improve annual predictions of oil, water, and CO_2 gas production by incorporating actual production data. • Evaluate changes in injection/production schemes through use of the reservoir simulator. • Evaluate need for additional infill wells based on performance of CO_2 flood.
01.02.02.03	Lab Test	• Special core analysis will be run on conventional cores by Texaco's research center. (relative permeability, residual oil saturation, and current saturation will be determined.) • On-site reservoir characterization will be made by description of drilled cuttings on horizontal section of horizontal well. • Reservoirs characterization will be refined.
01.02.02.04	Reservoir Simulation	• Reservoir simulation model will be improved with the incorporation of new permeability and porosity variations developed from data of new infill wells. • Simulation model will be used as a monitoring tool to evaluate changes in CO_2 injection patterns and gas stream composition. • A computer program will be developed to allocate CO_2 injection volumes and production volumes from wells in the project area.

NUMBER	TITLE	ACTIVITIES
01.02.03	Installation	
01.02.03.01	Drilling	• Drill 3 CO_2 injection wells, one being a horizontal injector. • Drill W. H. Stark -B- No. 36 as a CO_2 injector during 1992. • Drill H. J. Kuhn Tr. 1 Well No. 54 as a horizontal CO_2 injector during 1993. • Drill J. V. Polk -B- Well No. 39 as a CO_2 injector during 1994.
01.02.03.02	Workover	• Workover 12 wells to install stainless steel screen and liners and corrosion protected tubing and well heads. • H. J. Kuhn Tr. 1 No. 36 in 1992 as a water/CO_2 injector. • H. J. Kuhn Tr. 1 No. 14 in 1992 as a producer. • W. H. Stark -B- No. 10 in 1992 as a water/CO_2 injector. • H. J. Kuhn Tr. 1 No. 38 in 1992 as a producer. • W. H. Stark -B- No. 7 in 1993 as a producer. • J. V. Polk -B- No 2 in 1993 as a producer. • H. J. Kuhn Tr. 1 No. 17 in 1993 as a water/CO_2 injector. • W. H. Stark -B- No. 8 in 1993 as a producer. • H. J. Kuhn Tr. 1 No. 33 in 1993 as a producer. • H. J. Kuhn No 15R in 1993 as a producer. • H. J. Kuhn Tr. 2 No. 6 in 1993 as a producer. • J. V. Polk -B- No. 5 in 1994 as a producer.
01.02.03.03	Surface Facilities	• Install larger saltwater pump capable of pressuring up reservoir from 1850 psi to 3400 psig. • Construct new production platform to keep production separate from other lease production, and also to provide corrosion free separation of produced liquids. • Install a 330 hp injection compressor to handle 3-5 MMCFPD of produced CO_2 at pressures above 500 psig on a production barge near the project area wells during 1993. • Install a dehydrator on this same barge capable of drying 10-15 MMCFPD of produced CO_2 during 1993. (Additional capacity in anticipation of future requirements.) • Repair compressor on land 7000 ft from project site, to handle low pressure CO_2 gas at 30-50 psig suction pressure during 1993. (Discharge pressure 550 psig.) • Lay 6" fiberglass line from tank battery to land compressor for low pressure CO_2 produced gas during 1993. Lay 4" return line for compressed CO_2 during 1993. • Install high pressure flowlines or injection lines on all wells as wells are worked over. • Install a larger 660 HP recycle compressor during 1994 to handle an additional 10 MMCFPD of produced CO_2. • Install a new tank battery beginning in 1992 including 6-500 bbl oil storage tanks, 2-500 bbl water tanks, and a gunbarrel for separating the oil and water. • Additional electricity must be run to this tank battery. • Install a stainless steel production header system, HP and LP corrosion resistant separators (to separate liquids from gas), and gas metering facilities on tank battery to measure the CO_2 returning from the producing wells. • Safety control equipment will be installed to guard against oil spills in the event of equipment failure for tank battery.
01.02.04	CO_2	
01.02.04.01	Requirements	• Finalize CO_2 contract with third party CO_2 supplier. • Prepare DOT specification manual for pipeline. • Purchase CO_2 at a rate of 4.3 MMCFPD (250 tons/day), delivered to field at a pressure of 1200 psia.
01.02.04.02	Pipeline	• Build a 4.5 mile 4" pipeline from the third party supplier of CO_2 to the Port Neches Field.

NUMBER	TITLE	ACTIVITIES
01.02.05	EHSS Monitoring and Compliance	
01.02.05.01	Effluents, Wastes & Byproducts	• Surface Water: - Spill prevention control, containment and countermeasure plan (SPCC) will be revised as changes are made in the field. - Training by Regional Specialist - Site examination on daily basis; looking for leaks, spills, SPCC problems, handled by Area Operational staff. • Wastes generated: - Drilling Wastes: primarily mud and cuttings, solids control/dewatering device to be employed. Waste minimization, terminated as a source when drilling is completed. - Other production related wastes (oil filters, paper debris). • Waste stream characterization: area operational personnel will handle in conjunction with Division Reg. Spec. Outside environmental lab analysis of waste stream. • Application for waste transport/disposal permits from Texas Railroad Commission (RRC) and Texas Department of Health (TDH). • Air - Emissions Sources 1) 330 hp compressor 2) 660 hp compressor 3) Glycol dehydrator - CO, NO_x and VOC emissions 4) New tank batter - VOC's 5) New saltwater injection pump 6) 185 hp CO_2 injection 7) New high pressure and low pressure separators - fugitive VOC emissions - negligible quantity.
01.02.05.02	Greenhouse Gases & Air Toxics	• Emissions - Local increase in CO_2, CO, NO_2 emissions associated, primarily, with compressor site - impact anticipated. - Local VOC increase associated with tank battery site, fugitives loss associated with compressor/dehydrator site. - VOC emissions while locally increased will remain well below levels requiring permitting, expected to produce no discernable impact. - Dehydrator - possible source of air toxics emissions. - Release of air toxics controlled by installation of vapor recovery device when dehydration unit placed. - CO2 emissions in Port Arthur/Beaumomt area will decrease due removal of 4,300,000 scf (250 tons) of CO_2 per day from nearby chemical plant.
01.02.05.03	Socioeconomic	• Develop appropriate conservation/mitigation efforts in concert with Texas Parks and Wildlife officials in conjunction with regional management goals.

NUMBER	TITLE	ACTIVITIES
01.02.05.04	Compliance and Permitting	• A maintenance dredging permit is in effect until 12/31/92 for construction of bulkheads, wharves, and other structures and to perform oil and gas operations, and any dredging of existing channels. • Acquire Corps of Engineers permits for: - incoming CO_2 pipeline - other flowline and injection lines for 15 wells - platform construction for new tank battery - compressor barge site - new canal dredging for three new wells • Handling Procedures - Division environmental staff will handle Texas Air Control Board (TACB)/Clean Air Act compliance in conjunction with Area Operational personnel. - Permitting should not be required as emission levels will be sufficiently low. - Registration with TACB and annual emissions inventory for compressor/dehydrator barge. • Department of Transportation (DOT) Lines Tasks: - Define DOT jurisdiction lines. - Develop DOT manual for affected lines. - Personnel training r.e. DOT line maintenance and surveillance documentation/procedures. - Annual Report to DOT. - Maintain all DOT line test data for life of line. - In Texas the Railroad Commission - Gas Utilities Division handles DOT pipeline issues. • Health & Safety Issues - Issues related to this project to be emphasized from a health and safety standpoint: 1) Employee training a) high pressure gas/liquids b) cryogenic fluids c) confined spaces/anoxia 2) Emergency response plan developed for local and regional emergencies. - Tactical simulation using emergency plan has been conducted in Port Neches Field area. 3) First Aid/Safety Equipment associated with handling of low temperature related injuries. - Training by local safety representative • EHSS Compliance Capability 1) Established training programs related to employee safety - monthly safety issue training meetings at local level. 2) Environmental awareness training at local level on regular basis. 3) Use experienced environmental compliance staff at Division Office. Additional environmental professionals at industry laboratory (Texaco) located in close proximity - at Port Arthur. 4) Use experienced safety and health staff at Area and Division Offices. 5) Use administrative support available at Area and Division Offices for assistance in matters related to EHSS compliance. - Public and Governmental Affairs professional located at Texaco facility in Port Arthur. 6) Use extensive prior experience with EHSS compliance in Texas at local, Area, and Division offices. 7) Prepositioned stacks of booms, absorbent materials and other spill containment and clean-up supplies located in the Port Neches field.

NUMBER	TITLE	ACTIVITIES
01.03.00	**PHASE III - TECHNOLOGY TRANSFER**	
01.03.01	Management and Administration	
01.03.01.01	Administrative	• Assign tasks to Texaco, (SL) + SH/C personnel. • Coordinate "Outreach Program." • Arrange submission of articles to SPE. • Coordinate travel to conferences • Coordinate visits to site and engineering offices for DOE an FDD reservoir operators.
01.03.01.02	Deliverables/ Milestones	• Presentation at SPE National Convention in October, 1992 on overall project and site characterization. • Topical report on reservoir characterization and process design prepared for DOE by 4th quarter 1993. • Presentation of SPE paper on reservoir characterization and process design by 4th quarter 1994. • SPE paper on complete project, methodology and results by 4th quarter, 1996. • Topical report on project methodology and benefits to DOE. Completed tabular compilation of CO_2 potential in FDD reservoirs.
01.03.02	Information	
01.03.02.01	Compile	• Create data base for reservoir characteristics and list of reservoirs. • Review incoming information for application ad errors.
01.03.02.02	Manage	• Develop screening method for determination of CO_2 recoverable reserves in FDD reservoirs. • Determine reservoir characterization procedures necessary for a successful CO_2 flood. • Review needs for additional data.
01.03.03	Outreach Program	
01.03.03.01	Beneficiary Identification	• Identify reservoirs with similar drive mechanism and geology (with assistance of DOE/TORIS and LSU). • Identify estimates of recoverable reserves utilizing CO_2 flooding. • Hold symposium during 1995 to provide update on findings. Release topical report to DOE during 1st quarter, 1997.
01.03.03.02	Seminars/ Conferences	• SPE Presentations.
01.03.03.03	Publications	• SPE Paper on the process. • DOE Reports on the process in FDDR. • Reports/Paper on the refined CO_2 screening model for FDDR with weak or no aquifers. (MDOS)

The CO2 Projects Group was formed specifically to support development of oil reserves using CO2 flooding technology. The management and staff have many years of combined experience with this technology that will be applied to the Port Neches Project. The Project Engineer and will be responsible for coordinating and managing the reservoir characterization, recovery system design, and process design for the project. When the project move to the operational phase, Project Engineer will monitor performance and will consult with the Port Neches Production Engineer, who will report to Sour Lake Area Manager. Figure II.14 shows the organization of the Area Manager team.

Texaco's approach to managing of the project involves the Project Engineer, being directly responsible for daily management of project activities during the characterization, design, and installation phases (Figure 11.15). He will direct the remaining reservoir characterization work, the reservoir simulation analyses, and design of the recovery process. Technical support will be provided by the Assets Team and the Facilities Team as needed. For example, reservoir simulation support will be provided by the Assets Team. As a further example, the Project Engineer will identify the need and define the performance requirements for CO2 compressors. The compressor specification will be prepared by the Port Neches Facility Engineer and will be approved by the Project Engineer, EOR Manager and Area Manager before we purchase of the compressor.

After the project moves to the operational phase, primary responsibility for project operations will be with a Production Engineer, with help from a Production Supervisor. Both report to Area Manager. Daily operations will be run on a "business as usual" basis. This is, the project will be operated by current field personnel with same practices and procedures as that of any other Texaco site. However, the Project Engineer will continue to be the single point of contact for DOE, and he will project performance, technical reporting, and programmatic reporting. The environmental issues are a growing concern to Texaco. As such, we will have an Environmental Engineer coordinate permitting ad compliance plans with the installation and operations of the project. On project matters, he will report to the Project Engineer.

Texaco management oversight of the project will be the principal responsibility of the Enhanced Oil Recovery (EOR) Manager and CO2, Projects Group Manager. He will be in daily communication with the Project Engineer and the Project Team Leader on the progress and performance of the Port Neches Project. The EOR Manager will chair a Port Neches Oversight Committee, which will meet monthly to review project status and provide guidance to the project team. The other members of the committee will be Area Manager, Project Team Leader, Geologist on reservoir characterization, and Asset Team Leader. Records of these discussions will be reported to DOE in the project Monthly Status Report.

The cost-shared nature of the Port Neches Project will require that special attention be paid to interfacing with and reporting to DOE. To ensure that DOE receives the full measure of benefit from its investment in the project, Texaco will implement a number of specific actions. In addition to implementing the technology transfer program described in section II.G, we will submit all necessary monthly progress reports and an annual technical review. We will hold formal quarterly project review meetings, as necessary with DOE, to provide detailed updates of technical and programmatic status, and to involve DOE management in resolution of issues.

To ensure that costs are separated approximately and that necessary reporting requirements are met, a project procedures manual will be prepared specifically for the Port Neches Project. This manual will be submitted to DOE and will be used by all personnel involved in the project. It will specify all reporting requirements, and will include procedures for project charging and accounting, purchasing, and design engineering approval cycles.

In summary, Texaco has constructed a management approach that is effective and efficient for this project, and that contains the following features:

1. Maximum use of existing Texaco resources and infrastructure
2. Enhancements to our management procedures to ensure full compliance with DOE administrative, accounting, and reporting requirements

3. Specific management oversight activities

4. A full technology transfer program tailored to this project

5. An emphasis on a responsive DOE interface.

II.E.2.2. Relevant Experience

Texaco is an established industry leader in enhanced oil recovery technology. Our research laboratories have conducted research and developed technology services for our producing divisions for many years in all of the applicable advanced oil recovery technologies, including infill drilling, horizontal drilling, cross-linked gels, polymer flooding, and miscible (CO_2 flooding). We offer a number of products in these areas and regularly provide them to our producing divisions.

Of particular note is that Texaco regularly employs all of these advanced recovery technologies, and chooses the correct approach on a field-by-field basis depending on the geology and economics of the site in question. For example, we have drilled the first horizontal injection well in the state of Texas, and have drilled approximately 25 other horizontal wells. We are currently performing extensive steam flooding technology to the heavy crude oils of California. We are preparing to start CO_2 injection at three carbonate fields in West Texas. Carbon dioxide floods have been ongoing at the Paradis Field in South Louisiana since 1980. Based upon all these processes available to Texaco, we see the CO_2 miscible flooding process as the new wave of the future in FDD reservoirs.

Texaco has performed a number of projects in miscible CO_2, flooding, the most relevant of which are described in Sections II.B.2-3. A review of II.B.2-3 will illustrate the depth of our experience in miscible CO_2, flooding.

Our management support contractor, SAIC, is a large, well respected consulting company, with a major involvement in other DOE programs and in the energy industry as a whole. SAIC has over 13000 employees in over 200 offices across the nation, with over 2000 professionals working in energy and environment alone. SAIC's specific experience which greatly enhances our project

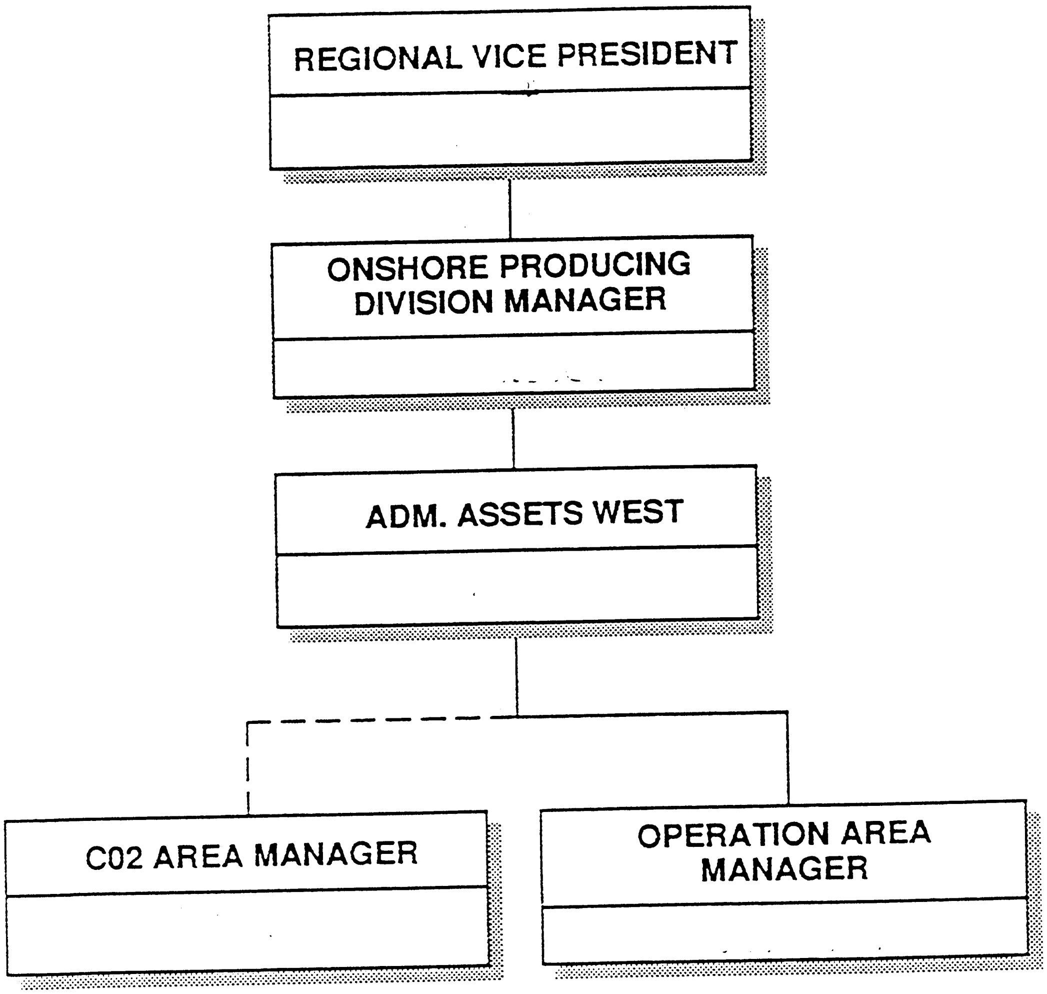


Figure II.12 TEPI Organizational Relationship to CO_2 Projects Group

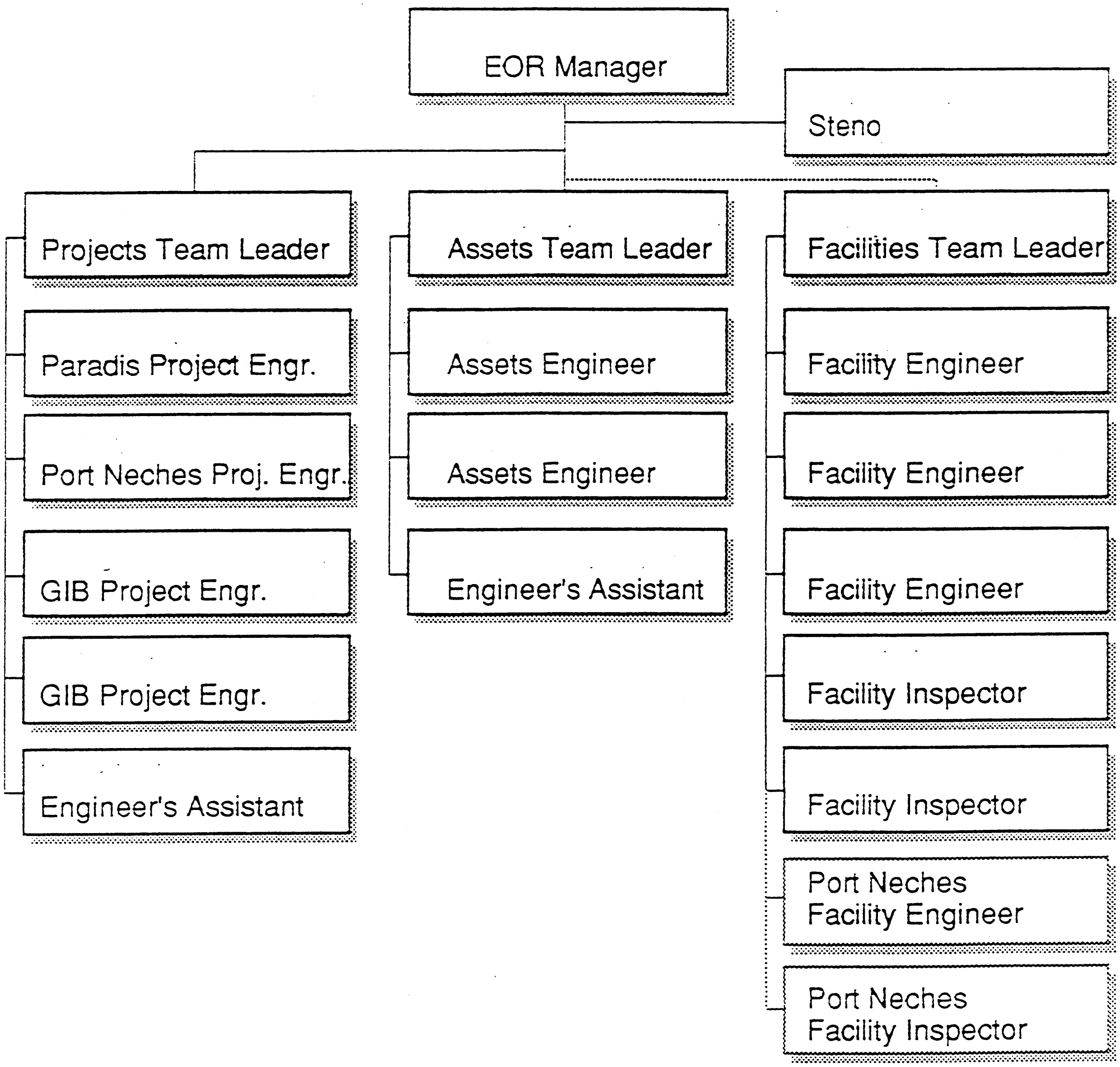
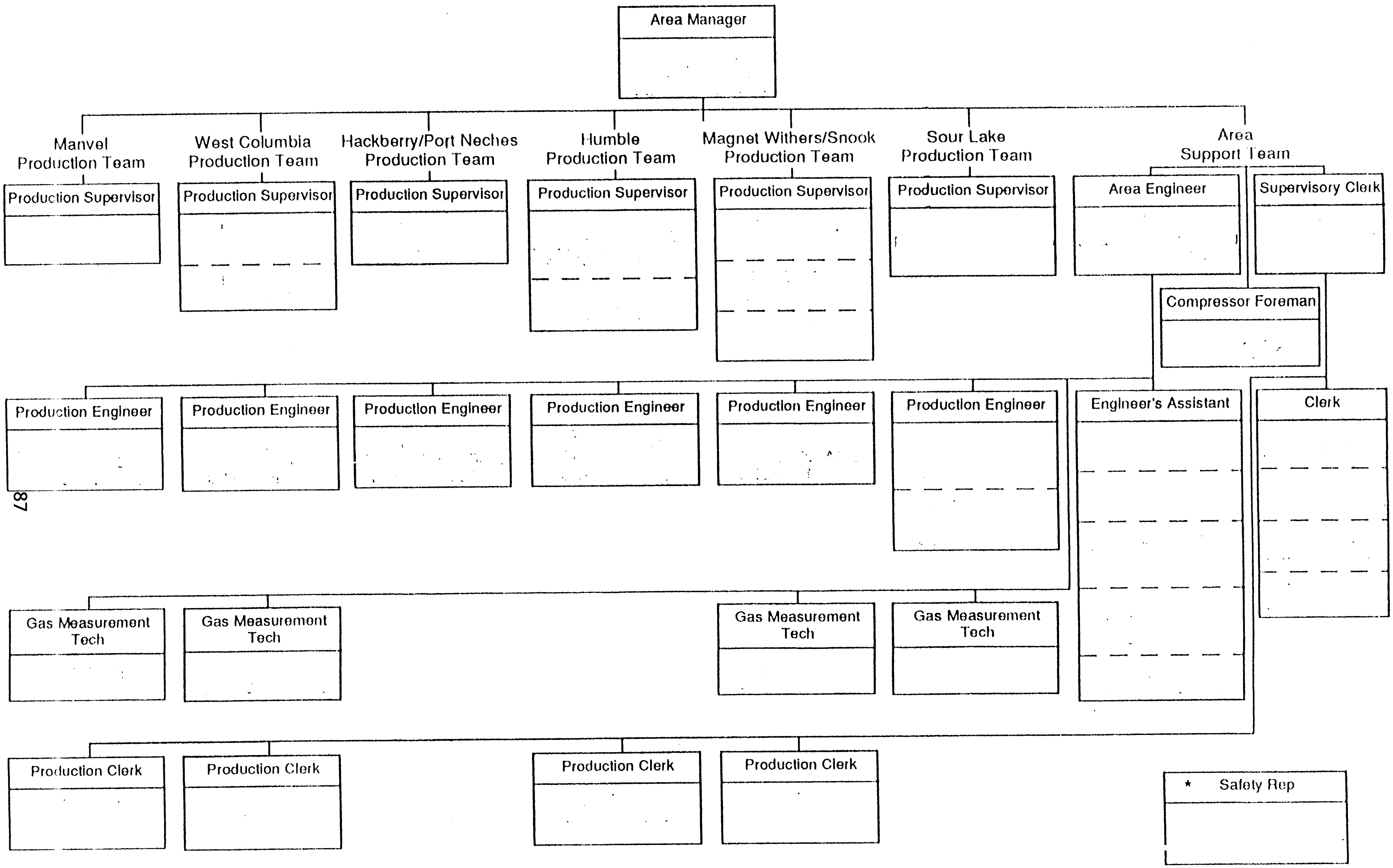


Figure II.13 Onshore Producing $C0_2$ Team



* Reports to Division and Located at the Area Office

** Transferred to Assets (West) Reservior Effective 8-1-90

Figure II.14 Texaco USA - Eastern E&P Region Onshore Producing Division Sour Lake Area

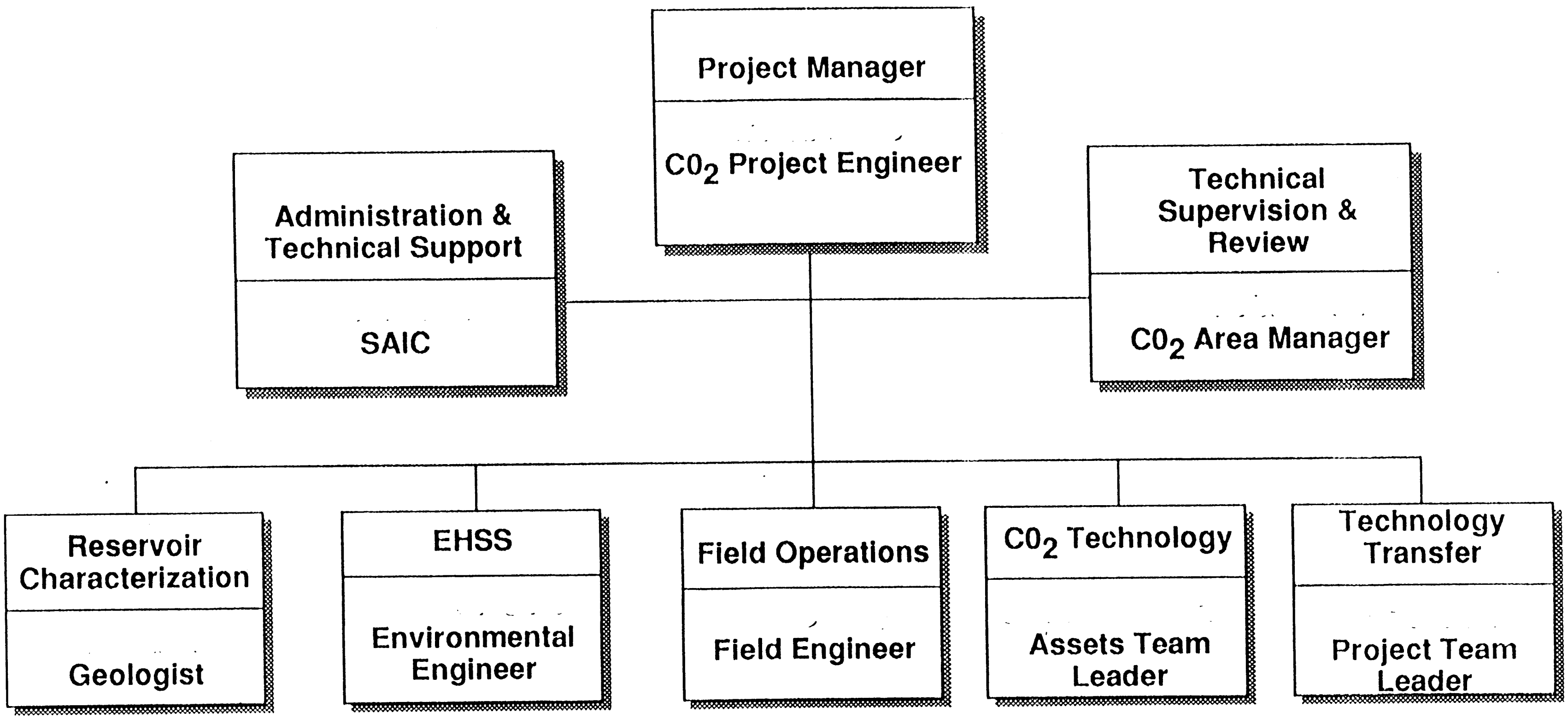


Figure II.15 Port Neches $C0_2$ Project Organization team is in supporting government-industry cost-shares. For three years, the same staff who will be supporting Texaco have been providing management support to ASARCO and the US Bureau of mines on a $20M + cost-shared project for in-situ leaching of copper from a copper oxide deposit that would be unminable by other methods. This project involves work in hydrology, geochemistry, and surface facility design and operation, which require skills and experience directly applicable to oil field development and production. SAIC has successfully performed exactly the same management support functions for ASARCO and U.S. Bureau of Mines on their cost-shared project as they will be providing to Texaco for the Port Neches Project.

II.E.2.3. Proposed Personnel

The roles and functions of the proposed key personnel were discussed in II.E.2.1 above. Our key personnel for this project are:

Project Engineer
CO2 Project Area Manager
Management Support
Reservoir Characterization Geologist
EHSS Support

II.E.2.4. Proposed Resources

The entire resources of the corporation will be available to support the Port Neches Project. The work will be done principally by our staff in the Onshore Producing Division, offices in Harvey, Louisiana, and Sour Lake, Texas. There are over 200 professional employees in this organization with experience in all of the disciplines required to profitably operate a large oil production operation. For high technology support services we have direct access to Texaco Research Laboratories in Houston, Texas. Finally, we have chosen SAIC as our management support contractor. SAIC is a $1.3 billion technology services company with an excellent reputation within the DOE and direct experience in performing management support for a $22 million government-industry cost-shared project.

II.E.11.8 Proposed Schedule and Milestones

The proposed overall project schedule is shown in Figures 11.16, 11.17 and 11.18.

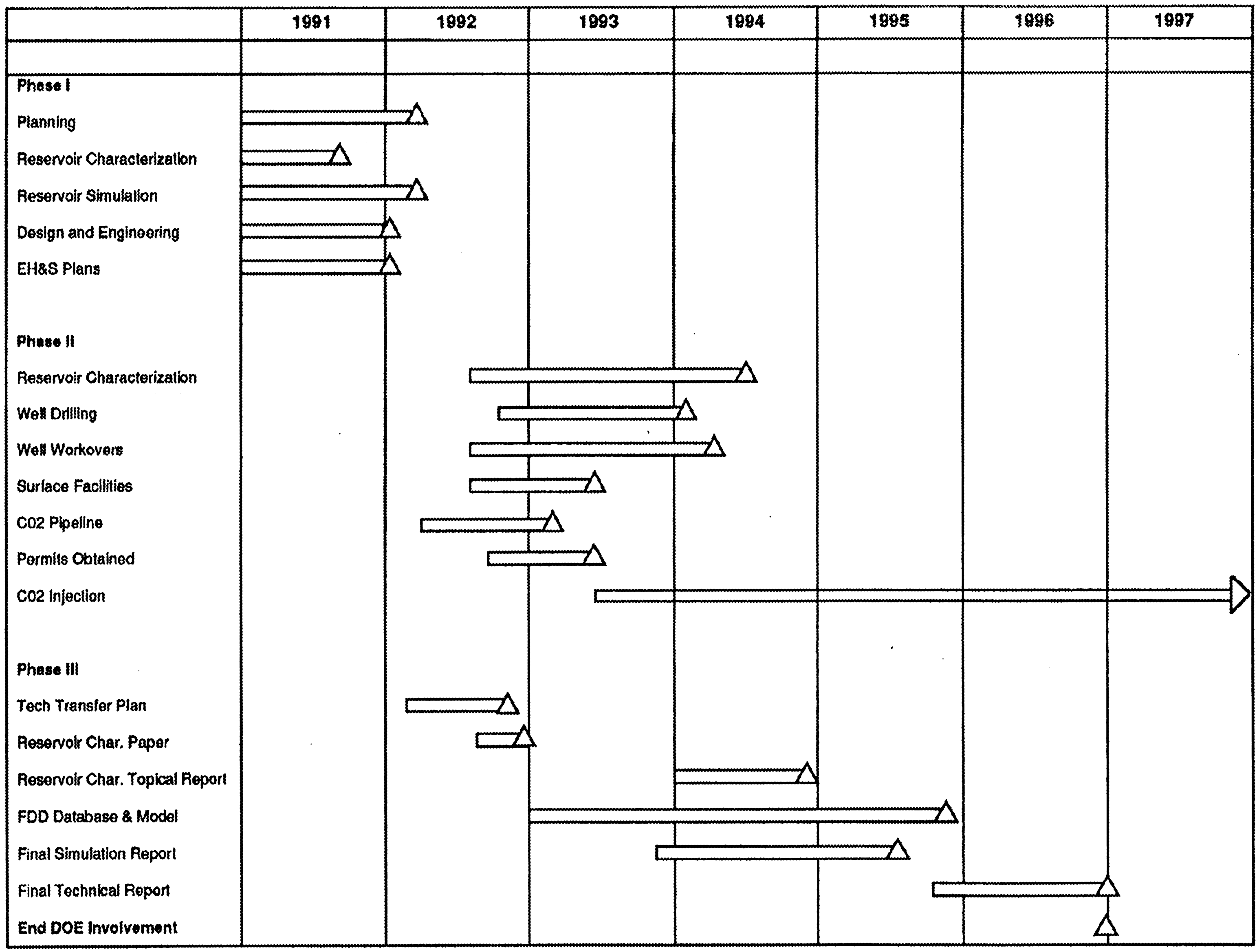


Figure II.16 Texaco Port Neches Miscible CO_2 Flood Demonstration Project Milestone Schedule

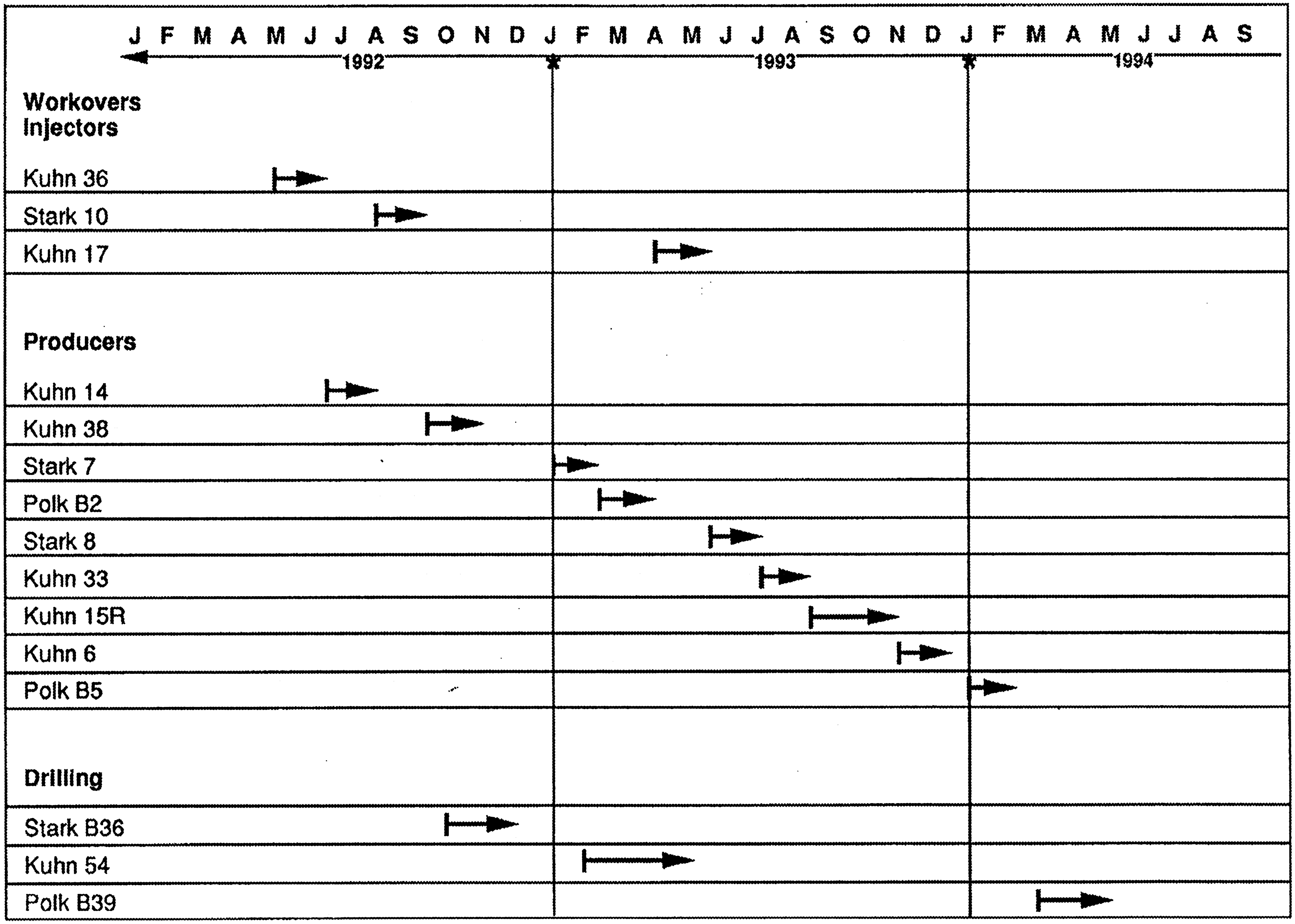


Figure II.17 Schedule at Port Neches Well Drilling and Workovers

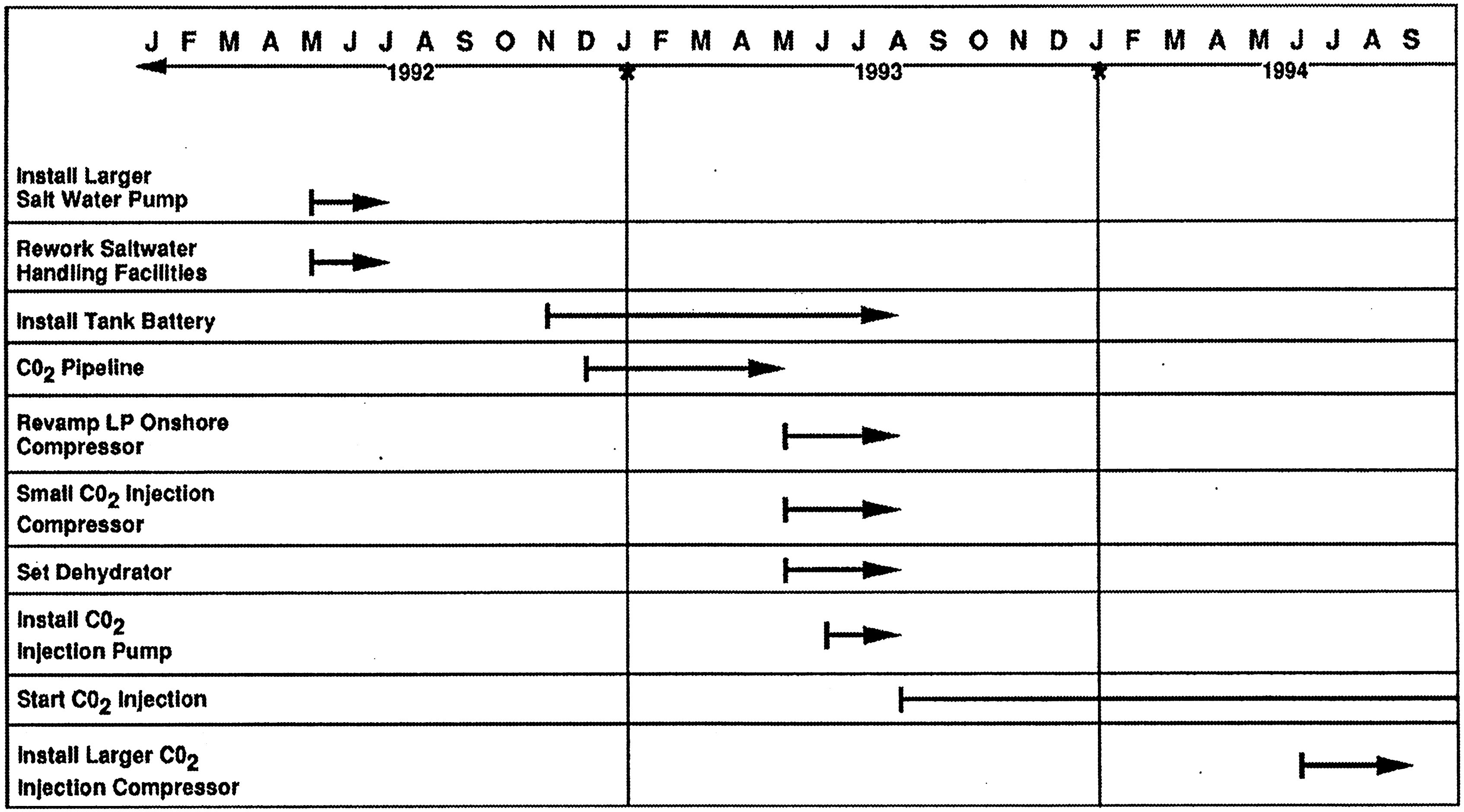


Figure II.18 Schedule at Port Neches Project Surface Facilities Installation

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II.F. EHSS AND OTHER SITE-RELATED ENVIRONMENTAL ASPECTS

The proposed project is not expected to present any significant environmental, health, or safety impacts. The amount of produced water will decrease over time due to the injection of CO_2 as opposed to water. Thus, the produced water currently filtered and discharged into tidal waters will be reduced over time. During drilling, the solid wastes produced will be precisely those associated with conventional extraction technologies, and the waste will be disposed of off site in accordance with prevailing regulations. Incremental airborne emissions will be very minor. As always, the handling of high pressure gases and volatile materials present some safety risk, but the risk will be limited by an aggressive inspection and maintenance program and by employee awareness training.

Disposal of produced wastes is handled in day-to-day operations throughout the oil industry. Adequate settling time in enclosed tanks allows for the oil, water, and produced solids to separate, which allows for pipeline sales (oil), tidal disposal (water), or transport to an offsite disposal site (solids) as required by the Texas Railroad Commission.

Texaco has in place a maintenance dredging permit for workovers and tank battery repairs in the Port Neches Field applicable through 1992. An extension for the current dredging permit will be requested along with additional permits for installation of new wells, flowlines, injection lines, the compressor site, and the tank battery site. Close contact with the Army Corps of Engineers and the U. S. Fish and Wildlife will be maintained. Our discussions with these groups indicate that mitigation may be required in some areas; however, Texaco will meet all requirements of these agencies.

Research Lab Support

Texaco's commitment to safeguarding the environment is a key guiding principle in our Producing Operations. The Exploration and Production Technology Department (EPTD) is keenly aware of the importance our Company places on environmental responsibility. Our team of engineering, chemical and geological professionals, specialize in consulting activities as they pertain to

II.F.I. Production and Handling of Effluents, Wastes and Byproducts

ILF.1.1 Surface Water

The Port Neches project will present a minor risk for pollution of surface water. An active spill prevention, control, and countermeasure plan (SPCC) is in place and will be modified as needed to address new construction and operations. The SPCC plan includes biannual training sessions for the operations staff year by a regulatory specialist. The site is inspected daily for leaks, spills, and other SPCC problems. A pumper is onsite to handle any accidental discharges. Texaco recently performed a tactical drill to insure that proper equipment and employee awareness exists to handle emergencies.

The discharge of produced waters will decrease over the life of the project, however, initially after CO2 injection begins approximately 2000 BWPD will be produced and discharged through tidal disposal. As the reservoir fluids are displaced, the amount of water will decrease over time. Water discharge fluctuations for this project are consistent with those which would be obtained by an active drilling or workover program in the field.

A water quality monitoring program is in place for tidal disposal performed in the field. The combined disposal from two permitted sites average 4200 BWPD. Texaco currently has two permitted tidal disposal sites in this coastal marshland area. Oil carryover is controlled by a series of separation and filtration devices which maintain oil levels below 22 ppm. Water samples from tidal waters are collected on a quarterly basis and measured by a lab for oil contamination. These reports are filed with the Texas Railroad Commission. Texaco meets or exceeds all state requirements for this disposal process. As rules and regulations change, Texaco is committed to continued compliance.

II.F.1.2. Solid Waste

The principal solid waste will be drilling wastes; primarily mud and cuttings. A solids control/dewatering device will be employed to minimize volume. This waste stream will be

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The principal solid waste will be drilling wastes; primarily mud and cuttings. A solids control/dewatering device will be employed to minimize volume. This waste stream will be terminated once drilling is completed. Other production related wastes (e.g. oil filters and paper debris) will be produced throughout the life of the project. Area operational personnel will handle all solid waste disposal requirements, and will be supported by a regulatory specialist as needed.

Solid wastes (e.g. produced sand) will be handled in a manner that will not affect the environment. Sand production occurs in day-to-day operations at minimal rates. Production of sand is minimized by the use of downhole gravel-packed screen and liners. A typical volume of produced sand per year would be about 1 to 2 barrels.

Tank bottom sludge will occur because of entrapped oil, water, and produced solids in the bottom of a tank. This may amount to a volume of 10 to 25 barrels per year. It is often treated by the use of de-emulsifiers and other treating chemicals. Permits for the transportation and disposal of the wastes will be obtained from the Texas Railroad Commission (RRC) and the Texas Department of Health (TDH). Application for the permits will be handled by area operational personnel, with assistance from Texaco Division Environmental Personnel.

As a result of drilling the three additional wells in this field, approximately 15000 cubic feet of solids will be generated. These cuttings will be transported to a disposal site and disposed of properly in accordance with all state and federal regulations. This procedure is standard for oil industry operations.

II.F.1.3. Airborne Emissions of Critical Pollutants

The principal sources of airborne emissions will operate throughout the lifetime of the project. These include sources of carbon manoxide (CO), nitrous oxide compounds (Nox) and volitile organic compounds (VOC) as follows:

- 165 hp CO2 pump (CO, Nox, VOC)
- 330 hp compressor (CO, Nox,VOC)

- 660 hp compressor (CO, Nox, VOC)

- glycol dehydrator (CO, Nox, VOC)

- tank battery (VOC)

- saltwater injection pumps (Nox, VOC)

- high pressure and low pressure separators (fugitive VOC emissions)

The two compressors, CO2 pump, and glycol dehydrator will be located at the same site and can be treated as a single source. The Division environmental staff will handle Texas Air Control Board (TACB) and Clean Air Act Compliance in conjunction with area operational personnel. Permits will not be required because the emission rates from all units will be well below regulatory limits. Permitting requirements would be necessary if total horsepower at a single site exceeds 2000 hp. All sources will be registered with the TACB and emissions will be inventoried annually in accordance with State regulations.

Air emissions of CO2, CO, and Nox, will result from running natural gas driven equipment totalling 1200 HP. This will amount to be less than 1 ton per day of air emissions, 249 tons per day below what is being removed as a result of this project.

Project related emissions of greenhouse gases and air toxins could be minimized by utilization of electric run pumps and compressors. Due to this field's water location and distance from an electric power-booster station, however, the use of natural gas is recommended. All compressors will have emission control devices as required.

II.F.1.4. Liquid Wastes

Liquid wastes (e.g. compressor lube oil and tank bottom sludge) will be disposed of in accordance with regulations of the Texas Railroad Commission. Permits will be obtained by area personnel.

Oil production will increase by roughly 800 BOPD, and will be handled by an additional 3000 barrels of storage capacity. This oil will be transported via pipeline to an oil refinery. Compressor lube oil waste will increase by approximately 50 quarts/year as a result of additional compression.

II.F.2. Reduction/Control of Greenhouse Gases and Air Toxins

Minor local increases in the emissions of CO2, CO, and NOx are expected in conjunction with operation of the compressor site. VOC emissions will increase at the tank battery site and there will be some fugitive emissions from the compressor/dehydrator, but total VOC emissions levels will have a negligible impact on the environment and remain well below the levels requiring permits. The dehydrator is a potential source of listed air emissions. Toxic releases will be controlled by installation of a vapor recovery device installed at the time the unit is installed.

As a result of this project, about 250 tons/day (4,300,000 scf per day) of CO2 which is currently vented to the atmosphere will be eliminated. A successful test of this process will allow for further reduction in CO2 emissions. Removal of 4,300,000 scf per day (250 tons per day) of carbon dioxide emissions from this Beaumont/Port Arthur area of Texas will be a welcome change in this high emission level area. There will be a net removal of greenhouse gasses and air toxins as a result of this project.

II.F.3. EHSS Compliance

II.F3.1. Health and Safely on Site

The principal onsite health and safety issues related to this project include:

- Employee training in:
  - handling high-pressure gases and liquids,
  - handling of cryogenic fluids, and
  - working in confined spaces with the risk of anoxia.

• A plan for response to local and regional emergencies.

• Siting of first aid and safety equipment necessary for handling low-temperature-related injuries.

The employee safety training program will be based on safety issues training meetings that will be held on site. Experienced health and safety staff located at Texaco local and Division offices will plan and conduct the training. The program will emphasize identification of hazards, strategies for minimizing risk, safe work practices, and the plan for handling accidents and injuries. The principal focus of the training and the principal danger at the site will be the handling of cryogenic fluids.

An emergency response plan will be developed for the project. A plan currently exists for ongoing operations at the site. The new plan will be based on the current plan, which will be expanded to address the new equipment and facilities. Tactical simulations have been performed for the Port Neches area using the current plan. Texaco maintains contact with local emergency and government officials to provide for coordination in an emergency.

The necessary safety equipment will be maintained on site. The equipment will be inspected monthly, and maintenance will be performed as necessary. Staff will be trained in the use of the equipment annually. The emphasis will be on low-temperature injuries.

II.F.3.2. Health and Safety Impact of Una

The potential safety impact of lines will be addressed through good design and an active inspection and maintenance program that will be developed before construction. Lines which fall under Department of Transportation (DOT) jurisdiction will be identified. For each applicable line, a DOT manual will be developed before the lines are laid. Using the manual, the staff on site will be trained to perform line maintenance, surveillance, and documentation in accordance with procedures acceptable to DOT and State regulators, in particular, the Texas Railroad Commission's, Gas Utilities Division. All line test data will be maintained for submission of the requisite annual reports to the DOT and TRC.

II.F.3.3. Permits

Permits will be obtained for the drilling of new wells, flowline installations, tank battery and compressor site installations during 1992. Texaco has flexibility in the locations of these new sites, therefore insuring the requirements for this project can be fulfilled. There are no anticipated problems in obtaining these permits.

Air emission permits will not be required for the compression and pumping equipment. Registration of this equipment will be performed in 1993. No new water discharge sites will be required, as the current site will be utilized. If regulations change during the project life, forcing underground injection, proper permits with the Texas Water Board and Texas Railroad Commission will be applied.

II.F.3.4. Stabilization of Produced Foods

Produced oil, water, and solids are stabilized by gravity separation with the use of a gunbarrel and series of tanks. Oil, water, and produced solids enter the gunbarrel from the projection well, where oil and water separate by density differences, then water enters a water setting tank and oil enters the oil storage tank. Water often carries solids out the gunbarrel and into a settling tank, which allows the solids to drop out. Clean water is filtered and checked for solids and/or oil particulate prior to disposal.

II.F.4. EHSS Risks and Impacts

II.F.4.1. Summary of Environmental Impacts

- Minor releases to surface water will be minimized by an active spill prevention program and by continuous retraining and inspecting.
- Produced water volumes will be reduced over time.
- Transportation and disposal of drilling wastes will be done in accordance with TRC and TDH requirements.
- The project involves only minor and standard sources of criteria air pollutants. These will be

registered and inventoried in accordance with State and Federal regulations but will not require permits.

- Minor listed air emissions from the dehydrator will be controlled by a vapor recovery device.
- Emissions of CO, NOx, and VOCs will be below the level of significance as greenhouse gases.
- Emissions of CO2 will be increased slightly at the project site, but the overall impact upon the environment will be a reduction in emissions. Texaco, through dredging efforts in the area, will assist in building levees and pathways recommended by the Army Corps of Engineers, when deemed appropriate. New technologies may be developed during this project which will eliminate some of the air emissions generated. Texaco will make every effort to explore these possibilities, and to meet all compliance standards.

II.F.4.2. Health and Safely Impacts

- The principal health and safety concerns focus on high pressure lines and the handling of volatile materials.
- The strategy for mitigation of health and safety risks will rest on an ongoing inspection and maintenance program and staff training.

Overall, the project will have negligible health, safety, and environmental impacts and will constitute no significant increment over conventional extraction.

II.G. TECHNOLOGY TRANSFER PLAN

II.G.1 Introduction

Technology transfer is the dissemination of the technologies and information gained in the proposed project to the oil industry so that the techniques developed can be applied to improve oil production. The transfer of technology is the final payoff for the Department of Energy. The lessons learned in this project would have limited value if they were applied only to the Port Neches field. By exporting technology Texaco learns at Port Neches, this project can serve the broad objective of helping at a national scale to mitigate declining production from U.S. oil reserves. In recognition of the critical importance of technology transfer Texaco and the project team are making a serious commitment to ensure that the lessons learned at Port Neches are widely disseminated.

The technology transfer program will emphasize two areas - 1) reservoir characterization and production constraints and 2) implementation of CO2 injection in post-waterflood FDD reservoirs. Texaco will work with interested parties to ensure that they have the complete and practical understanding necessary to identify where this method can be applied practically, what results should be expected, and how to go about planning and executing a CO2 injection program.

The objective of technology transfer will be accomplished in these two areas by an outreach program which will make the complete results of the project available to interested parties. The program will emphasize an open, communicative environment in which Texaco will publish and present the results in public forums and will welcome inquiries from companies exploring the approach.

II.G.2 Discussion of Relevant Business Aspects

Texaco will lead the effort to transfer the reservoir characterization methodology and technology. The Department of Energy and SAIC will play supporting roles. Texaco will prepare publications, presentations, and topical reports on their characterization work to date and new work done in the course of the project. The Department of Energy will function as the primary organ for dissemination of published materials. SAIC will support Texaco and DOE in preparing written materials and presentations and will provide logistics support for conferences and meetings. Characterization of the reservoir at Port Neches is largely complete, and Texaco has already determined that the field is a good candidate for C02 flooding. The carbon dioxide will be able to reach and mobilize oil which was not reached and/or effected by the waterflooding. In determining the viability of C02 injection and the amount of oil which will be recovered through injection, Texaco employed the concept of Minimum Displaceable Oil Saturation (MDOS). MDOS is a concept pioneered by Texaco as method for screening fields for C02 injection. MDOS is the minimum oil saturation that must exist in the pore space to successfully form an oil bank economically in a miscible flood.

The definition and derivation of an MDOS is the basic innovation in characterization of reservoirs for planning miscible C02 floods. Texaco's commitment to sharing information is demonstrated by their publication of the MDOS methodology and their extensive publication of results obtained in miscible C02 flooding in other formations. See, for example, Society of Petroleum Engineers (SPE) Publication 19636, ("Field-Derived Comparison of Tertiary Recovery Methods for Miscible C02 Flooding of Waterdrive and Pressure-Depleted Reservoirs in Southern Louisiana").

As the proposed project unfolds, and additional work is done on field characterization, Texaco will publish additional studies through the Society of Petroleum Engineers and make presentations at appropriate conferences. In particular, Texaco expects to make its first presentation of the analysis of the Port Neches field for miscible C02 flooding at the December 1992 SPE national convention in Washington, D.C.

Beyond publications in professional journals Texaco will prepare a detailed topical report on reservoir characterization at Port Neches for distribution through the Department of Energy. This report will be completed in the third quarter of 1993 and will describe the analysis used to determine the physical efficacy and financial viability of miscible C02 flooding.

This phase of the outreach program will be conducted at no cost to DOE or the project beyond the labor, materials, and travel necessary to prepare the reports and presentation materials. The information will be marketed at no cost, and Texaco will freely discuss the reports with interested parties who contact the company. No licensing is anticipated.

II.G.3. Transfer of the Results of the Field Demonstration

Transfer of the results of the field demonstration will require partnership between Texaco, the Department of Energy, SAIC, and the Louisiana State University. Texaco will collect the results of the field demonstration and prepare them for publication. The company will also prepare the final topical report summarizing the complete results of the project. The Department of Energy will be a clearinghouse for the published results and will make them available to the public. The Louisiana State University (LSU) will study ancillary reservoirs identifying fields with the same rock and production histories and characteristics to determine where the methods tested at Port Neches can be applied and what results will likely be obtained. The results of LSU's analysis will be used to update the TORIS database, again with DOE's assistance. SAIC will assist in the preparation of reports, other documents, and presentations, and will assist Texaco in the management of data and information collected in the course of the project.

The basis for successful transfer will be the identification of the fields and reservoirs likely to benefit from the new technologies. This will be determined on the basis of the geologic and engineering characteristics of the reservoirs. Once viable reservoirs have been identified, the owners and operators will be identified and contacted.

Each relevant owner/operator will receive a technology transfer package. This will include a complete description of the processes developed and employed at Port Neches and the results obtained. This will emphasize the analytical tools used to determine the viability of C02 flooding, and to plan and execute a C02 flooding program.

Updates to the DOE TORIS database will also serve to communicate the results of the project to the broader community of potential users as will the final topical report. In addition to these formal reports, Texaco will continue to discuss the work openly in professional forums, in SPE publications and in the Oil and Gas Journal, and through presentations at conferences.

The costs of this phase of the outreach program will be the labor, materials, and travel necessary to prepare the reports and presentation materials. The information will be marketed at no cost, and Texaco will freely discuss the reports with interested parties who contact the company. No licensing is anticipated. Other costs will include the cost of evaluating all FDD reservoirs to identify situations analogous to Port Neches. Part of this cost will go to purchasing data from third parties on operators and fields.

II.G.4 Schedule of Technology Transfer Activities

Technology transfer activities will begin at the outset of the project and continue for the duration. Key activities are scheduled as follows:

October 1992	Presentation at SPE National Convention on overall project and site characterization
4th Qtr 93	Topical report on reservoir characterization and process design to DOE
4th Qtr 94	Presentation of SPE paper on reservoir characterization and process design
4th Qtr 92 to 4th Qtr 96	Update and expand TORIS database
4th Qtr 96	SPE Paper on complete project, methodology, and results
1st Qtr 97	Topical reports on project methodology and benefits to DOE

Other papers and presentations will be made as appropriate. This effort will continue the active involvement of Texaco scientists and engineers in the professional community. Texaco's contributions to oil exploration and extraction technology have been amply demonstrated over many years. The company's long record of publication in professional journals and participation in professional conferences substantiates its commitment to making the technology developed at Port Neches available to everyone who can make use of it.

II.G.5 Plans, Capability and Commitment for Technology Transfer

Texaco is very familiar with the process of Technology Transfer in an oil company environment. Because of our far flung operations in the US and abroad, one of our major challenges is to be sure that the technology base maintained by our Exploration and Production Laboratories is effectively transferred to our operating divisions, such as the Onshore Producing Division. Our laboratories are continually conducting research and development into Enhanced Oil Recovery technologies to be sure that Texaco remains a technological leader in the industry. We have adopted a management philosophy of Quality Improvement that ensures that the staff in our Exploration and Production Laboratories have a strong customer focus with our operating personnel being the customer. We require regular meetings, seminars, and reviews involving both operating personnel and laboratory personnel to be sure that communications channels remain open, and we require that 75% of the funding for the Exploration and Production Laboratories comes from services bought by the operating divisions. In this way, Texaco maintains a balance between pure research and a customer oriented process of technology transfer from our laboratories to the operating divisions.

This management philosophy has worked, and it has made Texaco very adept at Technology Transfer internal to the company. We recognize that in order for DOE to attain a full measure of return on their investment in the Port Neches Project, we must turn our Technology Transfer capabilities outward and work with DOE's established Technology Transfer mechanisms as well as professional societies to be sure that knowledge and technology gained on the Port Neches

Project are effectively transferred to the industry at large. We believe that our approach to Technology Transfer outlined in this proposal will do that. To be sure that it is effective, we will develop a Port Neches Technology Transfer Plan, and submit it to DOE for further discussion and negotiation within two months of selection.

Texaco is committed to effective Technology Transfer from the Port Neches Project, and looks forward to working with DOE towards that end.