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AN EVALUATION OF KNOWN REMAINING
OIL RESOURCES IN THE STATE OF NEW MEXICO

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Christine Hansen
Executive Director
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EXECUTIVE SUMMARY

The Interstate Oil and Gas Compact Commission (IOGCC) has conducted a series of studies to evaluate the known, remaining oil resource in twenty-three (23) states. The primary objective of the IOGCC's effort is to examine the potential impact of an aggressive and focused program of research, development, and demonstration (RD&D) and technology transfer on future oil recovery in the United States. As a part of this larger effort by the IOGCC, this report focuses on the potential economic benefits of improved oil recovery in the state of New Mexico. Individual reports for seven other oil producing states and a national report have been separately published by the IOGCC. Several major technical insights for state and Federal policymakers and regulators can be reached from this analysis.

- At the conclusion of conventional recovery operations, two-thirds of the known original-oil-in-place will remain in New Mexico oil reservoirs.
- The remaining resource, over 10 billion barrels, is the target for future improved oil recovery techniques. However, a significant portion of this remaining oil resource has already been abandoned. An even greater portion is in imminent danger of abandonment if cost-effective and efficient recovery techniques are not applied.
- Resource abandonment will significantly impact the economic producibility of future production and reserves under improved oil recovery techniques. Major capital investments will be needed to reacquire the leases, rebuild the infrastructure, and more importantly, drill new wells to regain access to the New Mexico target resource.
- New Mexico's future oil production depends on the development of efficient and cost-effective oil recovery technologies, technology transfer to domestic producers, and the timely and successful application of such technologies, given the steady decline in New Mexico production and the accelerating level of well abandonment over the past decade.
- The effective transfer of existing technology could result in 430 to 640 billion barrels of new reserves from analyzed New Mexico reservoirs at oil prices ranging from \$20/B to \$28/B, potentially increasing the state's current proved reserves by 60% to 90%.
- Technology advances resulting from a focused RD&D effort could result in *additional* post-conventional reserves of 350 to 400 million barrels. The effective transfer of existing technology, coupled with the development and application of new technologies, could more than replace current proved reserves in New Mexico.
- Public sector revenues from future improved oil recovery activity would total between \$2.3 and \$4.3 billion given currently available recovery practices and oil prices of \$20/B to \$28/B. Technology advances could increase these totals by \$2 to \$3 billion over the same price range, with roughly 40% of the total flowing to the state treasury.

- Potential improved oil recovery would replace imports of foreign oil, keeping between \$9 billion and \$18 billion in the U.S. economy. This figure is only the direct cost of imports avoided due to increased domestic activity. The true value to the country is actually much higher due to multiplier effects as this money circulates in the economy.

The analysis presented in this report is based on the databases and models available in the Tertiary Oil Recovery Information System (TORIS). TORIS is a tested and verified system maintained and operated by the Department of Energy's Bartlesville Project Office. The TORIS system was used to evaluate 77% of the original oil-in-place (OOIP) in New Mexico reservoirs in a consistent manner and on an individual basis, the results of which have been aggregated to arrive at the statewide total.

Overall, well abandonments and more stringent environmental regulations could limit economic access to New Mexico's known, remaining oil resource. The high risk of near-term abandonment and the significant benefits of future application of improved oil recovery technology, clearly point to a need for more aggressive transfer of currently available technologies to oil producers. Development and application of advanced oil recovery technologies could have even greater benefits to the state and the nation. A collaborative, focused RD&D effort, integrating the resources and expertise of industry, state and local governments, and the Federal government, is clearly warranted. With effective RD&D and a program of aggressive technology transfer to widely disseminate its results, New Mexico oil production could be maximized. The resulting increase in production rates, employment, operator profits, state and Federal tax revenues, and energy security will benefit both the state of New Mexico and the nation as a whole.

I. OVERVIEW

A. THE PROBLEM: DECLINING NEW MEXICO OIL PRODUCTION

Over two-thirds of the oil discovered in the state of New Mexico will remain trapped in the reservoir at the conclusion of conventional oil recovery operations. The total known original oil-in-place in New Mexico has been estimated at over 15.8 billion barrels (Figure I-1). More than 4.3 billion barrels had already been produced at the end of 1991. Only 0.7 billion barrels of proved reserves are still producible under existing economic conditions, using currently available technologies. The remaining 10.8 billion barrels is the target for newer, more efficient recovery technologies and advances in geoscientific understanding that must be developed through an integrated public and private research effort.

Figure I-1

New Mexico Oil Resource

After Conventional Operations, Over Two-Thirds of the New Mexico Oil Resource Will Remain Unrecovered

Total Original Oil-in-Place: 15.8 Billion Barrels

Source: BPO TORIS, 1992
EIA, 1992
API/AGA, 1980

The urgency for technology development and its effective application by New Mexico oil producers has never been greater. The two factors that have combined to make technology development critical are:

- Declining state production and reserves. New Mexico oil production has declined by 45% from 1970 through 1991 (Figure I-2A). Crude oil reserves decreased by roughly the same percentage during the 1965 to 1980 time period (Figure I-2B). Although this decline has been reversed in recent years, reserves are still well below the historical peak.
- Increased level of well abandonment. The state of New Mexico currently produces oil from roughly 18,000 wells. Many of these wells are "marginal" wells producing at or near their economic limit. In a period of high production costs and low oil price, many of these wells are being abandoned. A recent analysis by the Department of Energy (DOE) has concluded that from 37% to 45% of the nation's remaining oil resources had been abandoned by the end of 1991.¹ Well abandonments will have a significant impact on economic access to the remaining resource for application of future improved recovery techniques. It is estimated that once a lease is abandoned, it will require an oil price *increase* of \$10/B to \$25/B to rebuild the infrastructure and drill replacement wells.² Such an economic burden will not likely be justified by the incremental oil revenues from future improved recovery techniques.

The future of New Mexico oil production and reserves depends strongly on the development and application of cost-effective and efficient technology. In the past, technology advances have made substantial contributions to New Mexico oil production. The development of new exploration techniques and secondary recovery technology has acted to reverse past production declines and has allowed New Mexico to maintain and increase its producible oil and gas resources. Oil producers in the state of New Mexico have also been involved in the application of enhanced oil recovery technology, particularly in the case of carbon dioxide flooding and improved waterflooding techniques. The opportunity exists for a program of RD&D, combined with an integrated program of technology transfer to all sectors of the New Mexico petroleum community, to arrest the decline in production and maximize recovery of the state's oil resource.

¹ "Abandonment Rate of the Known Domestic Oil Resource", U.S. DOE, Bartlesville Project Office, Bartlesville, OK (June 1990).

² Brashear, J.P. et al "Effect of Well Abandonments on EOR Potential," JPT, December 1991.

Figure I-2

New Mexico Production and Reserves

A) Annual Production

B) Reserves

B. THE OPPORTUNITY: OIL RECOVERY THROUGH ADVANCED TECHNOLOGY

The remaining oil resource constitutes a huge target for future recovery operations. The 10.8 billion barrels of known unrecovered oil in the state of New Mexico is of two types: mobile oil and immobile oil. Even though mobile oil is displaceable by water, it has been uncontacted or bypassed during conventional primary production or water flooding and thus remains unrecovered. Immobile oil is oil that is trapped in the reservoir pores by viscous and capillary forces and cannot be displaced by water.

The estimated unrecovered mobile oil (UMO) resource in New Mexico is 3.4 billion barrels. This oil is an important target for future improved recovery efforts. Several improved primary and secondary recovery processes (infill drilling, profile modification, and polymer flooding), collectively referred to as advanced secondary recovery (ASR), could be used in innovative ways to produce a substantial portion of this resource. These processes are relatively low in cost and could increase production levels quickly. While such techniques have already been used by some operators in selected reservoirs, continued research and aggressive technology transfer are critically needed to improve, streamline, and adapt these techniques to site-specific reservoir conditions and broaden their applications.

The 7.3 billion barrel remaining *immobile* oil resource in New Mexico is the target of a number of other recovery techniques. Miscible, chemical, and thermal recovery processes directed at producing immobile oil are referred to as enhanced oil recovery (EOR). While these processes generally require larger investments and higher operating costs than conventional recovery operations, they are capable of producing substantial volumes of incremental oil with significant economic benefits. Further advances in EOR technology are foreseeable if a focused, research-intensive approach is adopted to make process improvements ready for field application.

Technology Assessment Method

This assessment of the benefits of RD&D in oil recovery technology is based on the models and databases available through the Tertiary Oil Recovery Information System (TORIS). The TORIS methodology and analytical tools were originally developed by the National Petroleum Council (NPC)³ for its 1984 evaluation of nationwide EOR potential. DOE has since maintained and updated the system

³ National Petroleum Council, *Enhanced Oil Recovery*, Washington, DC, 1984.

through its Bartlesville Project Office (BPO).⁴ DOE has also upgraded the capability of the system to evaluate the nation's unrecovered mobile oil through ASR techniques. In this report, the future potential of EOR and ASR techniques are examined with the following key assumptions and considerations:

- A total of 94 New Mexico reservoirs accounting for over 12 billion barrels of original oil-in-place (77% of total known New Mexico OOIP as shown in Figure I-3), were individually analyzed for their EOR and ASR potential. No attempt is made to extrapolate the results to the remaining New Mexico resource not available in the TORIS database.
- Two levels of technology are considered: (1) implemented technology -- defined as the application of currently available post-conventional techniques; and (2) advanced technology -- defined as the improvements in process performance and applicability which are likely to occur over the next decade as the result of ongoing RD&D efforts.
- For each technology level, benefits were evaluated at several oil prices ranging from \$16/B to \$36/B (1991 dollars).
- All economic analyses reflect the current Federal tax structure and the specific oil production tax situation in New Mexico. The FY 1991 Federal EOR tax credit, as well as state EOR and ASR tax incentives are included in this analysis.
- All recovery potential evaluated in this report are for future new projects only, and they do not include incremental reserves from existing EOR projects. However, the expansion to the existing projects, if technically and economically feasible, are evaluated as part of future new projects in this report.

C. BENEFITS DERIVED FROM IMPROVED OIL RECOVERY

Potential incremental reserve volumes and resulting direct state and local revenues that could be generated through improved oil recovery (EOR and ASR) techniques under both the implemented and advanced technology cases are shown in Figure I-4. Implemented technology, if more widely applied, could add between 430 and 640 million barrels of incremental reserves across the \$20/B to \$28/B oil price range. Advanced technology applied to the same resource base could stimulate roughly 400 million barrels of additional incremental resource for a total of 830 million to 1.0 billion barrels beyond currently proven reserves. In effect, improvements in process performance and application could nearly double the reserves possible under implemented technology conditions. This clearly provides a major justification for a focused RD&D and technology transfer program.

⁴ *Producing Unrecovered Mobile Oil: Evaluation of Potential Economically Recoverable Reserves in Texas, Oklahoma, and New Mexico*, DOE, May 1990.

Figure I-3

New Mexico Oil Resource

Data Coverage of EOR and ASR Analyses

Source: BPO TORIS, 1992
 EIA, 1992
 API/AGA, 1980

The potential for expanded application of EOR techniques using implemented technology is limited if prices remain at or below \$20/B; incremental EOR recovery at this price would total only about 36 million barrels. However, implemented technology EOR could add 127 million barrels of reserves at a higher oil price of \$28/B. At this oil price, advances in EOR technology could stimulate an additional 11 million barrels of incremental reserves. This means that a total of 138 million barrels of potential EOR recovery exists under the two levels of technology for the analyzed reservoirs at a price of \$28/B.

Reserve additions attributed to ASR techniques are more substantial but are impacted much less by oil price changes than EOR. About 395 million barrels of ASR reserves could be added in the implemented technology case at an oil price of \$20/B, growing to 513 million barrels at an oil price of \$28/B. Research on process improvements, specifically improved polymer flooding and profile modification combined with geologically targeted infill drilling, could increase ASR potential by 70% to 100%. With advances in technology, incremental ASR reserve additions could total 350 million to 400 million barrels more than implemented technology over the price range analyzed.

Future advanced oil recovery activities will generate revenues for New Mexico and the Federal treasury through increased production taxes, oil industry-related sales taxes, and corporate and personal income taxes. The revenue estimates in this study consider only direct revenues from recovery activities in the analyzed reservoirs, and exclude any additional indirect benefits from multiplier or "ripple" effects within the state or national economy. Under implemented technology at \$20/B, newly implemented improved oil recovery projects in New Mexico could directly generate \$0.94 billion in state revenues. At the same oil price, advanced technology could generate an additional \$0.86 billion, for a total of \$1.8 billion in state revenues (Figure I-4). At an oil price of \$28/B, application of currently available EOR and ASR technology could contribute \$1.9 billion to the New Mexico public treasury while the application of advanced methods could increase these revenues by an additional \$1.1 billion to a total of \$3 billion.

Increased production from EOR and ASR could offset oil imports, which in turn would reduce the national trade deficit, and increase national economic activity. The value of the oil produced, the product of reserves and their effective oil price, is a simple measure of New Mexico's contribution to reducing imports. As shown in Table I-1, this figure could total between \$9 billion and \$18 billion under the implemented technology scenario, over the \$20/B to \$28/B range. Advanced technology could further decrease imports by an *additional* \$8 billion to \$10 billion. The additional value of domestically produced EOR and ASR generates significant direct economic activities as capital spending, profits, royalties, and taxes are circulated through the U.S. economy rather than spent internationally to buy foreign oil.

Figure I-4

Potential Impact of Advanced Technology

A) Reserve Additions

B) Direct State and Local Revenues

Table I-1

Summary of Benefits from Technology Advances in EOR and ASR in New Mexico

Oil Price and Technology Level	Potential Reserves (Million Barrels)	Incremental State and Local Revenues (\$ Billions)	Incremental Imports Avoided** (\$ Billions)	Increased Federal Revenues (\$ Billions)
At \$20/B				
Implemented Technology	431	0.94	8.59	1.41
<u>Advanced Technology*</u>	<u>399</u>	<u>0.86</u>	<u>7.93</u>	<u>1.08</u>
Total	830	1.80	16.52	2.49
At \$24/B				
Implemented Technology	583	1.49	13.90	1.97
<u>Advanced Technology*</u>	<u>379</u>	<u>1.00</u>	<u>9.05</u>	<u>1.36</u>
Total	962	2.49	22.95	3.33
At \$28/B				
Implemented Technology	640	1.89	17.78	2.44
<u>Advanced Technology*</u>	<u>365</u>	<u>1.14</u>	<u>10.18</u>	<u>1.63</u>
Total	1,005	3.03	27.96	4.07

*Advanced is incremental over implemented technology.

**Imports Avoided = Reserves times effective wellhead price; to the extent that 1 barrel of domestic oil replaces 1 barrel of imported oil, imports avoided estimates the reduction in foreign trade deficit.

D. CONCLUSIONS

The development, testing, and wide-scale application of currently available improved oil recovery technologies could stimulate incremental reserves ranging from 430 million to 640 million barrels from New Mexico's largest, most mature reservoirs at oil prices of \$20/B to \$28/B. With the technology advances resulting from focused RD&D, an additional 350 million barrels to 400 million barrels could be produced over this price range using EOR and ASR techniques. Even with the successful development and application of these technologies, however, about 5.6 billion barrels of immobile oil would still remain in the analyzed reservoirs as a long-term target for future advances in EOR processes, and 1.6 billion barrels of mobile oil would remain as a long-term target for future advances in ASR processes (Figure I-5). While this target is substantial, it unfortunately will not remain a target indefinitely. Well

abandonments have already limited economic access to a portion of the resource. Timely application of new recovery technology is crucial if economic access is to be maintained.

The results of this analysis have important policy implications. Domestic oil production generates significant direct revenues to New Mexico and to the Federal government and substantial additional indirect benefits to both the state and national economies. In addition to stimulating reserves, production, and economic activity, the application of improved oil technology would enhance the nation's energy security. The integrated efforts needed to achieve these goals should include:

- Collaborative RD&D;
- Aggressive technology transfer; and
- Appropriate tax and regulatory policies at the state and Federal levels.

Figure I-5

New Mexico Remaining Oil Resource After Advanced Technology Recovery

A collaborative RD&D effort between the oil industry, universities, state and local governments, and the Federal government focused on improving advanced oil recovery technology and its application in key geologic settings would benefit operators, the state of New Mexico, and the entire nation. With sound planning and clear, attainable goals, state policies can be effectively integrated with Federal and private programs to dramatically increase production to the benefit of both the state and the nation's treasuries, economies, and citizens. State and Federal tax incentives can be instituted, or where already in place could be modified to improve their effectiveness, in order to help domestic EOR and ASR projects compete with foreign investment opportunities. In addition, regulatory policymakers could design regulations which reflect both the true risks to health, safety and the environment and the economic risk of resource loss through abandonment.

II. BACKGROUND AND OBJECTIVES

A. TRENDS IN NEW MEXICO OIL PRODUCTION AND RESERVES

Overall, oil production in New Mexico has declined significantly over the past twenty years (Figure II-1). While New Mexico production was on the upswing throughout most of the 1960s, production peaked at nearly 130 million barrels in 1969. Apart from a gain of six million barrels in 1978, New Mexico's oil production dropped annually from 1970 through 1982. Over those twelve years production declined 45%, hitting a low of 71 million barrels in 1982. Unprecedented high oil prices sparked a modest recovery from 1983 to 1985, with annual production reaching nearly 80 million barrels. The precipitous drop in oil price thereafter triggered a resumption of the production decline; by 1990, New Mexico's production had sunk to a low of 67 million barrels, a level not seen since 1952. Such a production decline is evidence of the increasing maturity of New Mexico's oil fields. Production in 1991 saw an increase of 5%, due primarily to 1989-1990 drilling. The increase is almost entirely due to the development of the North Dagger Draw field in Eddy county. Annual production from the Upper Pennsylvanian Cisco and Canyon formations in this field has increased from 6.2 to 16.7 million barrels during the 1990 to 1992 period. South Dagger Draw field has added about 3.5 million barrels of annual production over the same time period.¹

Reserves levels in New Mexico have also been on the decline from highs established in the 1960s (Figure II-2). In 1961, reserves were estimated at close to 1.1 billion barrels. While they dropped nearly 18% by 1965, they once again exceeded 1 billion barrels by 1966. The next ten years proved to be difficult ones for New Mexico's operators, as production eroded reserves to just 535 million barrels, less than 50% of their prior level. Over the past 15 years, New Mexico's reserves have recovered somewhat, due to record high oil prices and application of waterflooding and EOR in the eastern portion of the state. By 1991, five consecutive years of reserves increases left 721 million barrels of remaining recoverable oil, giving New Mexico ten years of future production at current rates. New Mexico's trend of increasing reserves is not seen in any of the other major oil producing states.

¹ New Mexico Energy, Minerals, and Natural Resources Department, Oil Conservation Division, Artesia, New Mexico.

Figure II-1

New Mexico Crude Oil Production (1950 - 1991)

Figure II-2

New Mexico Crude Oil Reserves (1950 - 1991)

The number of producing oil wells and reserves per producing well for New Mexico over the past thirty years have fluctuated (Figure II-3). In the early 1960s, total wells rose sharply by close to 4,000, and production increased. In the early 1980s, well numbers rose by a similar amount. One significant difference between the two periods was the level of reserves per producing well. Whereas the 1960s had almost 50,000 barrels of reserves for each producing well, the 1980s have seen that number shrink to about 35,000 barrels of oil. Such decreases, given roughly the same number of wells, indicate a maturing resource where operators are drilling wells for intensive development of old fields rather than making new discoveries.

Compounding the problem of reduced reserves is the increasing reliance on stripper wells to maintain current production. In 1970, just 8% of New Mexico's production came from wells producing fewer than 10 barrels of oil per day (Figure II-4). By 1990, that number had climbed to 21% and will most likely continue to rise in the future. These wells are more sensitive to oil price shocks, and prolonged periods of low prices can lead many operators to abandon economically marginal or unprofitable wells. Recent figures from New Mexico indicate that well abandonments have risen over the past ten years. Since 1980, over 9,000 producing stripper wells have been abandoned, with over 1,700 having been abandoned in 1987 after oil prices had plummeted.

Clearly, these declining trends have significant implications for the employment and economic activity stimulated by the New Mexico oil industry. In 1981, nearly 28,000 people were employed in the state's oil and gas industry, but only 21,000 people were employed in those fields in 1991 (Figure II-5). Over the same period, the gross value of oil produced in the state declined from a high of almost \$3 billion (constant 1991 dollars) in 1980 to less than half that amount in 1991. Such a decrease in the value of production renders a significant amount of lost tax revenue that hurts the state's overall economic well-being (Figure II-6).

Revenues from production taxes on oil and gas reached a peak of \$479 million (constant 1991 dollars) in 1981, only to decline by over 50% to \$230 million in fiscal year 1991 (Figure II-7). The loss of oil and gas revenue has had a significant impact on total state tax revenues. In fiscal year 1984, when oil prices and production were higher, oil and gas production taxes contributed more than 27% to state tax revenues (Figure II-8). This percentage has fallen dramatically, to less than 13% of total tax revenues in fiscal year 1990.

Figure II-3

Figure II-4

Figure II-5

**Total Oil and Gas Employment in New Mexico
(1970 - 1991)**

Figure II-6

**Annual Wellhead Value of New Mexico Oil and Gas
Production (1961 - 1991)**

Figure II-7

**New Mexico Oil and Gas Severance Taxes
(FY1971 - 1991)**

Figure II-8

**New Mexico Oil and Gas Severance Taxes as a
Percent of Total State Taxes (FY1971 - 1990)**

Despite declines in New Mexico's oil production and reserves, the oil and gas industry can continue to play a vital role in the state's economy. At the conclusion of conventional primary and secondary operations, large portions of New Mexico's known original oil-in-place (OOIP) will remain unrecovered in reservoirs that are currently discovered and mostly developed (Figure II-9). The total known OOIP in New Mexico is estimated at over 15.8 billion barrels. Of this, 4.3 billion barrels have been produced and 721 million barrels were recognized as proved reserves at the end of 1991, for a total ultimate recovery by conventional technology of just over 5.0 billion barrels. This figure accounts for only 32% of the original oil-in-place. Nearly 11 billion barrels (68% of the known OOIP) remains unrecovered as a target for newer, more efficient extraction technologies. This unrecovered resource can be divided into two main components: mobile oil and immobile oil. In New Mexico, 3.4 billion barrels of unrecovered mobile oil (UMO) makes up the target for a number of advanced primary and secondary recovery processes, collectively referred to as advanced secondary recovery (ASR). The 7.3 billion barrels of remaining immobile oil represent the target for a number of tertiary extraction techniques, defined as enhanced oil recovery (EOR). Recovery operations directed at each of these resources could play a critical role in sustaining New Mexico's oil production well into the next century and in reducing the nation's dependence on foreign oil. A brief discussion of the analyzed EOR and ASR processes is contained in Volume X, Appendix A.

B. IMPROVED RECOVERY ACTIVITIES TARGETING THE REMAINING OIL RESOURCE

The oil remaining after conventional primary and secondary recovery lies in two defined regions within each reservoir: the swept and the unswept zones. In the swept zone of the reservoir, conventional operations have recovered a significant portion of the original concentration of oil. The oil remaining in this swept zone is trapped in the reservoir pore spaces or on the surface of the pores by capillary and surface tension forces. Additional flooding with water can produce very little of this oil; the swept zone is at the "waterflood residual" level of oil saturation. The volume previously occupied by displaced oil now contains injected water (or, in some cases, natural gas). In their current stage of development, EOR processes are generally expected to reach only those portions of reservoirs previously swept by conventional techniques. Proven enhanced recovery processes are classified into three EOR categories: gas-miscible, chemical, and thermal.

Figure II-9

New Mexico Oil Resource

In the unswept zone of the reservoir, conventional recovery processes have not swept the pore space, and the oil saturation can range from low to high depending upon the primary recovery mechanism (e.g., pressure depletion or water drive). The objective of many infill drilling programs, improved waterflooding projects (profile modification), and other reservoir management techniques is to contact the oil in the unswept zones. Only after these zones have been swept by water are EOR operations generally considered feasible.

1. Enhanced Oil Recovery

Four field scale CO₂-miscible injection projects are currently underway in New Mexico: Phillips' units in the Vacuum, Maljamar, and Leamex fields, and Conoco's unit in Maljamar.² All of these projects are Permian Basin carbonates which have characteristics similar to those fields under CO₂ flood just across the border in West Texas.

The earliest of these floods was at Phillips' Vacuum field in Lea county, where CO₂ injection began in the East Vacuum Grayburg-San Andres Unit (EVGSAU) in 1983. Total ultimate CO₂ injection is estimated at 230 billion cubic feet with about 43% of that total being recycled.³ The CO₂ is purchased from the Llano pipeline, a spur off of the Cortez CO₂ pipeline which passes across New Mexico connecting the McElmo Dome CO₂ field in southwestern Colorado with the Permian Basin fields of West Texas.

Since CO₂ injection began at EVGSAU, the decline in oil production has been reversed. Phillips shut in general producers to control premature breakthrough of CO₂ until the recycling facility became operational in 1987. Several profile modification processes (e.g., polymer or foam) have also been implemented to control the flood front. Phillips predicts that CO₂ injection will continue at least through 2001, and that an incremental recovery of 20.7 million barrels, or 8% of the OOIP in the 4,900 acre project area, will result from the miscible flood.⁴

Phillips and Conoco both have CO₂ injection projects underway in the Maljamar field. Conoco began with a pilot project in 1978 and expanded to a larger scale in 1989. Phillips initiated a pilot in late

² Moritis, Guntis, 1992, "EOR Increases 24% Worldwide: Claim 10% of U.S. Production," Oil and Gas Journal, April 20, 1992, p. 51-79.

³ Brownlee, M.H. and Sugg, L.A.: "East Vacuum Grayberg - San Andres Unit CO₂ Injection Project: Development and Results to Date," Paper SPE 16721 presented at the 62nd Annual Technical Conference, Dallas, TX, Sept. 27-30, 1987.

⁴ *Ibid.*

1989 and is currently evaluating an expansion.⁵ Phillips also operates another CO₂ injection project initiated in the Leamex field in 1991.

Chemical processes have limited application in the major oil zone in Southeastern New Mexico where zones are predominately carbonate deposits. However, smaller fields in the North Western region could hold some potential for recovery by chemical flooding. As currently understood, however, future chemical EOR potential is limited.

Two thermal processes have been tested in New Mexico: Tenneco's 1980-1981 in-situ combustion pilot in the Hospah field in the San Juan Basin and a conventional steam injection pilot by Rio Petro Inc. at the O'Connell Ranch Unit in Emadalupe county in 1981.⁶ The results of both of these applications were discouraging. Although its application to New Mexico reservoirs may be limited compared to the other EOR processes, thermal recovery remains the predominant EOR technique in the U.S. and could, ultimately, have wider applications in New Mexico.

2. Advanced Secondary Recovery

Mobile oil remains in the reservoir after conventional recovery for a variety of reasons. Foremost of these is reservoir heterogeneity, the complex variation of rock properties among zones in the producing interval. Reservoirs may consist of a large number of individual compartments, reflecting internal heterogeneity. These compartments are formed by depositional processes that originally formed the reservoir, or by diagenesis or tectonic activity that later altered the rock bodies. Exceedingly complex reservoirs may have compartments formed by all of these processes. At a given well spacing, some compartments containing oil are not in pressure communication with existing producing wells. At wide well spacings, much of the rock volume in a heterogeneous reservoir will not be contacted by existing wells, leaving large volumes of oil at or near original pressure and saturation. These compartments provide a major target for infill drilling and future recovery operations conducted at closer spacing.

⁵ Moritis, Guntis, 1992, "EOR Increases 24% Worldwide: Claim 10% of U.S. Production," Oil and Gas Journal, April 20, 1992, p. 51-79.

⁶ Pantz, J.F. et al, "Enhanced Oil Recovery Projects Data Base," NIPER, Bartlesville, OK, April 1992.

Mobile oil also remains in reservoir compartments that have been contacted, but inefficiently swept by secondary recovery methods that utilize existing well configurations. At wide well spacings, significant volumes of oil are areally bypassed due to small-scale variations in reservoir continuity, to the higher viscosity of oil than injected water, and to permeability variations within the reservoir. The effectiveness of water injection is further limited by vertical layering in the reservoir. Water preferentially enters the more permeable layers of the reservoir, leaving the less permeable rock layers unswept at relatively high remaining oil saturations.

Several geologic factors influence the volume, distribution, and potential future production of unrecovered mobile oil (UMO). A major factor commonly influencing recovery potential is reservoir genesis, or the type of system that originally deposited the reservoir rock. Internal reservoir architecture is profoundly affected by the depositional system of the initial reservoir sediment, which controls the distribution of different types of rock "packages," and by the pore structure that plays host to later diagenetic rock and fluid alterations. Other important geologic factors include trap style and source rocks. Reservoirs that have common depositional histories may have very similar internal reservoir architecture, but will be modified by post-depositional diagenesis. That modification will vary from basin to basin depending on geohistory.

Recovery of remaining mobile and immobile oil from known fields is a highly cost effective method for increasing oil production. A large portion of these new reserves have resulted from improved primary and secondary recovery methods, including implementation of waterflooding and pressure maintenance programs, drilling of additional wells to improve reservoir contact, and selective recompletion of existing wells to improve performance. Several distinct methods for producing UMO have emerged: infill drilling to tap uncontacted reservoir compartments, recompletion of production and injection wells to contact and sweep previously bypassed portions of the reservoir, polymer flooding to overcome unfavorable waterflood injection fluid characteristics, and profile modification to reduce the permeability contrast between reservoir layers. These techniques are all tested and proven methods for producing mobile oil remaining in the reservoir.

Some portion of the oil bypassed at current spacing can be recovered by well-designed, advanced waterflooding techniques, and significant portions of this oil could be recovered with the combined application of both polymer injection and infill drilling. Two polymer augmented waterflood projects have been reported in New Mexico, both in parts of the Vacuum field. Initiated in 1983, Conoco's 240 acre

project was discontinued because it was an economic failure. However, Phillips' unit in the same field showed promise.^{7,8} Few infill drilling and profile modification processes were reported in the literature.

Taken alone, infill drilling, polymer flooding, and profile modification are effective processes for producing mobile oil; they are often even more effective when applied in combination, which allows the processes to complement one another. For example, polymer injection and profile modification can be used to increase the waterflood sweep efficiency not only in previously contacted compartments, but also in compartments newly contacted by infill drilling. These synergies maximize the cost-effectiveness of mobile oil recovery and encourage the coordinated, multiple application of techniques in selected reservoir settings.

There are several other processes and recovery techniques which were not included in this analysis which may have potential in New Mexico. Application of these techniques would further increase potential recovery and add to the estimates contained in this analysis. Immiscible gas and nitrogen gas EOR projects could enhance New Mexico oil recovery. In addition, improvements in reservoir management and improvements in waterflood patterns, waterflood rates of injection, and the timing of inception of waterfloods show significant potential as recovery techniques. To the extent that these techniques and others currently being transferred (i.e., injection water compatibility) improve potential oil recovery, the results presented in this report will be understated.

C. OBJECTIVES OF THE PRESENT STUDY

The present study analyzes the incremental reserves, public sector revenues, and statewide economic activity that could result from the implementation of the improved EOR and ASR techniques described above. The potentials for EOR and ASR production are evaluated separately, and each is considered for two technology levels: *implemented technology*, which assesses recovery potential given the widespread application of currently available technology, and *advanced technology*, which assesses

⁷ Moritis, Guntis, 1992, "EOR Increases 24% Worldwide: Claim 10% of U.S. Production," Oil and Gas Journal, April 20, 1992, p. 51-79.

⁸ Hovendick, M.D., "Development and Results of the Hale-Mable Leases' Co-Operative Polymer EOR Injection Project, Vacuum (Grayburg-San Andres) Field, Lea Co., New Mexico, SPE Paper 16722 presented at the 1987 Annual Tech-Conference in Dallas, Texas, September 27-30, 1987.

the impact of the effective application of potential technological advances. Comparison of the results of these two evaluations provides the basis for assessing the benefits of improved technology provided by RD&D. All of the analyses are conducted over a range of crude oil prices from \$16 to \$36 per barrel (in constant 1991 dollars). This price range encompasses the long-term prices likely to prevail over approximately the next 30 years.

Ninety-four reservoirs, accounting for over 12 billion barrels of original oil-in-place (nearly 77% of the total known resource in New Mexico), were included in this analysis. These reservoirs contain 3.4 billion barrels of remaining oil resource (Figure II-10). The 2.6 billion barrels of UMO is the target for application of ASR processes and 5.8 billion barrels is the target for application of EOR processes. To achieve the required level of application, and therefore receive the maximum benefits of both levels of technology assessed in this report, it is critical that state and local governments, the Federal government, and the oil industry work collaboratively to: (1) effectively transfer to operators currently available technology (implemented technology), and (2) develop a focused RD&D program to improve recovery methods (advanced technology) and subsequently transfer those methods to a broad public-private audience. The results and conclusion will provide valuable insights for state and Federal policymakers in their efforts to maximize domestic production and improve the nation's energy security.

Figure II-10

New Mexico Remaining Oil Resource After Conventional Recovery Operations

III. APPROACH TO THE ANALYSIS

A. INTRODUCTION

This analysis was performed using the Department of Energy's Tertiary Oil Recovery Information System (TORIS) developed for the 1984 National Petroleum Council (NPC) analysis of the nation's enhanced oil recovery (EOR) potential.¹ Although TORIS was originally designed to evaluate EOR potential only, the system's capabilities have since been expanded to incorporate evaluations of the unrecovered mobile oil (UMO) resource, the target for advanced secondary recovery (ASR). The upgraded TORIS system assessed the recovery potential of immobile oil and UMO in the United States. The following sections in this chapter will briefly discuss the:

- Development of TORIS;
- Enhancement of TORIS to evaluate the UMO resource;
- Scope of the current analysis;
- Adaptations to TORIS for this analysis;
- Estimation of benefits, costs, and economic impacts; and
- Limitations of the analytical approach.

B. GENERAL METHODOLOGY: THE NPC BASIS

In March 1982, the U.S. Secretary of Energy requested that the NPC prepare a report on the nationwide potential and the economics of incremental EOR. The NPC is the official petroleum industry advisory committee to the Secretary. Members of NPC, who are appointed by the Secretary, represent all segments of petroleum interest, such as production, refining, marketing, and environmental, and include many chief executive officers. The NPC is supported entirely by the voluntary contributions of its members.

In response to the Secretary's request, the NPC mounted a two-year effort that consumed more than 50 professional man-years and nearly \$7 million of in-kind services. EOR experts from industry (majors, independents, service companies, and consulting firms), universities, government, and private, non-profit organizations participated. The NPC EOR study committee utilized and built upon data bases

¹ National Petroleum Council, *Enhanced Oil Recovery*, Washington, DC, 1984.

of individual reservoir characteristics and computer models that were under development by the U.S. Department of Energy's (DOE), Office of Fossil Energy. After augmentation, adaptation, and validation, the data bases and models were remanded to the DOE's Bartlesville Project Office (BPO) for maintenance, updating, and subsequent application. These data bases and models are components of a larger system, the Tertiary Oil Recovery Information System (TORIS).

By the agreement of the Assistant Secretary for Fossil Energy, the present study enjoys access to TORIS and the assistance of BPO, although its participation is limited strictly to providing the data base, models, and assistance for the technical analysis. The BPO and DOE neither contribute to nor endorse the study design or the interpretations presented in this report. The approach used by the NPC and in the present study to evaluate the EOR resource consists of the major phases listed below.

1. Reservoir Data Compilation. Detailed data describing the properties of the individual, significant oil reservoirs are compiled. Numerous public and private sources of information are consulted to complete and validate the reservoir data base. The principal elements of the TORIS data base are displayed in Table III-1. Representatives of the operating companies review the data elements of each reservoir at least three times for consistency and accuracy; automated validity checks are performed on the entire data base.
2. Resource Screening Models. Each reservoir is subjected to a screening process designed to identify the technical applicability of the respective EOR processes under what the NPC defined as "implemented," or currently available, technology. The specific criteria applied to screen each EOR process are shown in Table III-2. In addition, the reservoirs are screened under what the NPC defined as "advanced" technology, available through focused research and development. Table III-3 displays the technical criteria for "advanced" EOR technology.
3. Process Performance Models. Each reservoir that satisfies the technical criteria is then analyzed by a detailed process performance model at each level of technical applicability. The models for each process have been previously reviewed in detail and calibrated to actual field results. NPC study committees review and test this calibration. The models are reservoir-specific and, therefore, estimate incremental oil production from EOR as a function of reservoir properties and process design for each reservoir independently. Incremental production is that which is recovered in excess of production by conventional primary and secondary techniques at current field conditions.
4. Economic Evaluation. Each reservoir is then evaluated for its economic feasibility by estimating the income attributable to the incremental EOR production and the investment, operating costs, and taxes required to support the implementation of the process as designed and installed in the field. Detailed costing algorithms reflect EOR design (both "implemented" and "advanced"), reservoir depth, region, and other factors. The energy component of each cost element is adjusted to reflect the oil price being analyzed. A

Table III-1

Key Elements in the Current TORIS* Reservoir Data Base

• <u>Original Volumetrics</u>   -- Original Oil-in-Place -- Reservoir area -- Net thickness -- Porosity -- Initial water saturation -- Initial oil saturation -- Initial formation volume factor • <u>Current Volumetrics</u>   -- Current oil saturation (swept zone) -- Current formation volume factor • <u>Fluid Data</u>   -- Oil gravity and viscosity -- Connate water viscosity -- Connate water salinity -- Initial GOR -- Current GOR -- Injection water salinity -- Crude oil fractions & properties
(being added)	• <u>Geologic Variables</u> -- Lithology -- Depth -- Temperature -- Original and current pressure -- Permeability -- Permeability variation index -- Clay content -- Gross thickness -- Dip angle -- Geologic age code -- Presence of gas cap, faults, shale breaks -- Geologic play, depositional system, trap type -- Areal and vertical heterogeneity descriptors -- Pay continuity (estimated) • <u>Development & Performance Data</u> -- Recovery efficiency -- Cumulative production -- Annual production -- Current injection rate -- Cumulative volume of injectant by type -- Well spacing -- Number of producing & injecting wells -- Water cut

*Tertiary Oil Recovery Information System, maintained and operated by the Bartlesville Project Office of the U.S. Department of Energy

Table III-2

Screening Criteria for EOR Candidates - Implemented Technology Case

Screening Parameters*	Units	Chemical Flooding		Miscible Flooding	Thermal Recovery	
		Surfactant	Alkaline	(Carbon Dioxide)	Steam	In-Situ Combustion
Oil Gravity	°API	---	<30	≥25	10 to 34	10 to 35
In-situ Oil Viscosity (μ)	cp	<40	<90	---	≤15,000	≤5,000
Depth	Feet	---	---	---	≤3,000	≤11,500
Pay Zone Thickness (h)	Feet	---	---	---	≥20	≥20
Reservoir Temperature (TR)	°F	<200	<200	---	---	---
Porosity (ϕ)	Fraction	---	---	---	≥0.20***	≥0.20***
Permeability Average (k)	md	>40	>20	---	250	35
Transmissibility (kh/ μ)	md-ft/cp	---	---	---	≥5	≥5
Reservoir Pressure (PR)	psi	---	---	≥MMP**	≤1,500	≤2,000
Minimum Oil Content at Start of Process ($S_o X \phi$)	Fraction	---	---	---	≥0.10	≥0.08
Salinity of Formation Brine (TDS)	ppm	<100,000	<100,000	---	---	---
Rock Type	---	Sandstone	Sandstone	Sandstone or Carbonate	Sandstone or Carbonate	Sandstone or Carbonate

* Other criteria of a geological and depositional nature were also considered. Generally, reservoirs with extensive faulting, lateral discontinuities, or overlying gas caps are not prime candidates for field-wide EOR application. These factors were considered during the manual screening step when they could be identified.

** MMP denotes minimum miscibility pressure, which depends on temperature and crude oil composition.

*** Ignored if oil saturation (S_o) X porosity (ϕ) criteria are satisfied.

Source: NPC, 1984.

Table III-3

Screening Criteria for EOR Candidates - Advanced Technology Case

Screening Parameters*	Units	Chemical Flooding		Miscible Flooding	Thermal Recovery	
		Surfactant	Alkaline	(Carbon Dioxide)	Steam	In-Situ Combustion
Oil Gravity	°API	---	<30	≥25	---	---
In-situ Oil Viscosity (μ)	cp	<100	<100	---	---	≤5,000
Depth	Feet	---	---	---	≤5,000	---
Pay Zone Thickness (h)	Feet	---	---	---	≥15	≥10
Reservoir Temperature (TR)	°F	<250	<200	---	---	---
Porosity (ϕ)	Fraction	---	---	---	≥0.15***	≥0.15***
Permeability Average (k)	md	>10	>10	---	≥10	≥10
Transmissibility (kh/ μ)	md-ft/cp	---	---	---	---	---
Reservoir Pressure (PR)	psi	---	---	≥MMP**	≤2,000	≤4,000
Minimum Oil Content at Start of Process ($S_o X \phi$)	Fraction	---	---	---	≥0.08	≥0.08
Salinity of Formation Brine (TDS)	ppm	<200,000	<200,000	---	---	---
Rock Type	---	Sandstone or Carbonate	Sandstone	Sandstone or Carbonate	Sandstone or Carbonate	Sandstone or Carbonate

* Other criteria of a geological and depositional nature were also considered. Generally, reservoirs with extensive faulting, lateral discontinuities, or overlying gas caps are not prime candidates for field-wide EOR application. These factors were considered during the manual screening step when they could be identified.

** MMP denotes minimum miscibility pressure, which depends on temperature and crude oil composition.

*** Ignored if oil saturation (S_o) X porosity (ϕ) criteria are satisfied.

Source: NPC, 1984.

discounted cashflow analysis is performed for each reservoir at a number of oil prices and minimum rates of return.

5. Technology Development. For each reservoir that is determined to be economic at a given price, the performances of the applicable EOR processes are compared. Each reservoir is then assigned the process producing the greatest quantity of incremental oil. In the NPC assessment, the reservoirs are then scheduled for development on the basis of their relative economic attractiveness and time-phased against a series of supply and environmental constraints. This procedure is modified somewhat in the present study, as described below.

The NPC reported its findings on a national basis for four oil prices, ranging from \$20 to \$50 per barrel, three minimum rates of return (zero, ten, and twenty percent), and two levels of technology performance -- "implemented," meaning available at present, and "advanced," meaning available in the future due to successful completion of currently ongoing RD&D. The present study uses the NPC reservoir data base, models, and methodology just as the NPC developed them, except as described in sections C and E. The NPC methodology is described at length in its final report.²

C. BUILDING ON TORIS: THE EVALUATION OF UNRECOVERED MOBILE OIL RESOURCES

TORIS evaluations have historically focused on the recovery of immobile or waterflood residual oil. In 1988, TORIS' capabilities were expanded to include an evaluation of the UMO resources in Texas, Oklahoma, and New Mexico.³ This expansion was accomplished by enlarging the system to consider the recovery potential of extended primary and secondary recovery operations in unswept portions of the reservoir, in a manner consistent with the current capabilities to analyze the tertiary recovery target (residual oil in previously swept zones). The system development and initial limited applications that were completed under the DOE UMO study are reported in detail in a topical report by the DOE.³

² *Ibid.*

³ ICF Resources Incorporated and the Bureau of Economic Geology, University of Texas at Austin, *Producing Unrecovered Mobile Oil: Evaluation of Potential Economically Recoverable Reserves in Texas, Oklahoma, and New Mexico*, prepared for: U.S. Department of Energy/Office of Planning and Environment/Office of Fossil Energy and Bartlesville Project Office, 1989.

Since 1989, the TORIS ASR models have been upgraded to more accurately describe and evaluate the UMO resources. The enhancements included the following:

- Development of an infill drilling model which processes five-spot waterflood to five-spot infill as well as five-spot waterflood to nine-spot infill;
- Development of a methodology to determine key reservoir heterogeneity elements needed for modeling infill drilling potential. The heterogeneity elements are "reservoir continuity" and "Vertical Permeability Stratification Index" (Dykstra-Parson coefficient). The methodology relies on the history match of production data to determine the heterogeneity elements;
- Validation of the infill drilling model and history match methodology on nine actual field results as well as results of a black oil simulator;
- Integration of a newly developed infill model with other models in TORIS to process infill drilling in combination with polymer flooding or profile modification; and
- Validation of criteria for implemented as well as advanced technology infill drilling.

A preliminary draft report of all developmental work is available through the U.S. Department of Energy, Bartlesville Project Office. The draft report is currently being finalized, and it will be available to the general public in the near future.

UMO, the target for advanced primary and secondary recovery operations, consists of oil that is uncontacted or bypassed during conventional production that can be displaced from the reservoir by waterflooding. "Uncontacted oil" refers to oil trapped in isolated compartments in reservoirs uncontacted by wells at current spacing, while "bypassed" oil has been contacted by existing wells but unswept by secondary recovery processes. The volume, location, and properties of the UMO depend on the geologic history of the reservoir, the fluid characteristics of the oil, and the drilling and development history of the reservoir.

Potential incremental oil recovery and related economic benefits are estimated for the three processes currently used to improve mobile oil displacement. These processes are referred to as advanced secondary recovery (ASR) and include: infill drilling, profile modification treatments (permeability contrast reduction), and polymer-augmented waterflooding. A modified polymer-waterflood predictive model is used to evaluate each process. Selected combinations of these processes are also evaluated in this study.

Consistent with TORIS EOR evaluations, the analysis of UMO considers both current technology and advanced technology. The advanced technology analysis estimates the potential improvement in recovery possible after successful RD&D. For polymer flooding and profile modification treatments, advances in technology are projected to increase both the reservoir temperature and the formation salinity thresholds that currently limit the application of these processes. Table III-4 shows the process technical screens that are used in evaluating reservoirs for polymer flooding and profile modification treatments under current and advanced technology scenarios.

Table III-4
Screening Criteria for
Advanced Secondary Recovery Processes

	<u>Polymer Flooding*</u>		<u>Profile Modification</u>	
	<u>Current</u>	<u>Advanced</u>	<u>Current</u>	<u>Advanced</u>
Reservoir Temperature (°F)	<200	<250	<180	<250
Formation Brine Salinity (ppm)	<100,000	<200,000	<100,000	<200,000
Permeability (md)	>20	>10	>20	>10
Oil Viscosity (cp)	<100	<150	<100	<150
* Source: NPC, 1984				

Infill drilling potential is also evaluated under implemented and advanced technology scenarios. Current knowledge of reservoir heterogeneity limits drilling to highly favorable reservoirs where blanket-pattern drilling at uniform spacing can yield a profit. Increased continuity in the implemented technology case is estimated by the reservoir-wide average improvement in continuity possible with a reduction in spacing to one-half the current level. The advanced technology scenario assumes that improved geologic description would target infill wells to more promising segments of each reservoir. The TORIS models represent this assumption by dividing the reservoir into two parts, a more continuous (homogeneous) region and a less continuous (heterogeneous) region. Each region is then separately analyzed to determine

its economic potential for infill drilling at subsequent one-half reductions in well spacing down to five acre spacing, or one-eighth of current spacing, the maximum reduction evaluated in this study. The specific criteria for both the implemented technology and the advanced technology infill drilling is shown in Table III-5. The entire methodology (data, models, highgrading, and analytical systems) was developed and implemented in a manner fully compatible with the existing TORIS structure.

Table III-5

Screening and Approach for Advanced Technology Infill Drilling

Technology Level	Criteria
Implemented	<ul style="list-style-type: none"> - 5-spot waterflood to 5-spot infill - 15% minimum real rate of return - Minimum well spacing of 10 acres before infill drilling - One drill down
Advanced	<ul style="list-style-type: none"> - 5-spot waterflood to 5-spot infill - 10% minimum real rate of return - Highgrade into homogenous and heterogeneous portions - One drill down in homogeneous portion - Up to three drill downs in heterogeneous portion - Well spacing after infill greater than 5 acres

D. SCOPE OF THE ANALYSIS

The cases selected for this analysis include six oil price assumptions and two levels of technology application. The cases are run, first incorporating either EOR or ASR processes individually, and then in combination. TORIS selects from five EOR recovery methods and five ASR methods for each reservoir in the database. A reservoir could be assigned only one EOR process and/or one ASR method for each case considered.

The nominal crude oil prices (West Texas intermediate adjusted for transportation costs and gravities less than 40° API) range from \$16/B to \$36/B in \$4 increments, all stated in constant 1991 dollars. The prices are selected to bracket the likely prices over the next 30 years. A minimum real (after inflation) rate of return of 10% is used to estimate discounted cash flows and project profitability for all analyses. In addition, a risk premium is also considered depending on the EOR or ASR process and the

level of technology. The risk premium is modeled as an increase in the hurdle rate as shown by the following table. The risk premium was recommended by the TORIS peer review committee.

Table III-6

Risk Premium For Implemented and Advanced EOR and ASR Processes

	Cost of Capital	Risk Factors		Hurdle Rates	
		Implemented Technology (%)	Advanced Technology (%)	Implemented Technology (%)	Advanced Technology (%)
Alkaline	10	15	0	27	10
Surfactant	10	15	0	27	10
In-Situ	10	15	5	27	16
Polymer	10	5	0	16	10
Profile Modification	10	5	0	16	10
CO ₂ -Miscible	10	5	0	16	10
Steam	10	5	0	16	10
Infill Drilling	10	5	0	16	10

At each oil price, two technology cases are analyzed; the "implemented" and the "advanced" case. Implemented technology reflects the applicability and level of performance of the respective processes (EOR or ASR) which are currently available. Advanced technology considers the likely improvements in process performance and applicability that can be achieved within the next decade if a focused, effective RD&D program is successfully completed.

All cases are analyzed in detail to examine their impact on estimated oil reserves, oil production, state and Federal revenues, and the state and national economies. The results of these analyses, addressing the benefits from incremental production, are reported in Chapters IV and V which discuss the effects of EOR and ASR processes for implemented technology and advanced technology, respectively.

E. ADAPTATIONS FOR THE PRESENT STUDY

Several adaptations to the NPC approach were necessary to conduct the present analysis. None is a significant departure from the NPC methodology.

1. Data Editing and Additions

Based on a lengthy data search using state and library sources, the NPC reservoir data have been reviewed and updated for 94 of the largest New Mexico reservoirs, accounting for nearly 77% of estimated original oil-in-place (OOIP) in the state. The reservoirs represented in the data base include oil zones in every region of the state. The largest reservoirs are more completely represented in the data, but reservoirs as small as 5 million barrels are also analyzed in the study. The data base is, therefore, believed to be representative of the diverse oil producing formations across New Mexico. Data from the Energy Information Administration on the production of oil, gas, and water from 1970 to 1992 has been added for all reservoirs, thereby permitting decline curve analyses (used in the timing algorithm, discussed below) and validation of the estimated ultimate conventional recovery.

2. State and Federal Taxes

The present study uses current tax structure along with the actual tax rates in the TORIS economic models. The Federal taxes are estimated based on the new corporate tax rules established by Congress in the Tax Reform Act of 1986 and signed into law in October 1986. This law provides for a 34% marginal rate on corporate income taxes and changes the depreciation schedules and expense rules. In addition, the present study includes the new Federal EOR tax credit as passed by Congress in FY91. The new Federal EOR tax credit provides a credit equal to 15% of all qualified enhanced oil recovery costs on projects that began or were significantly expanded after December 31, 1990. The "qualified enhanced oil recovery costs" are defined as tangible property investments, intangible drilling and development costs, and purchase costs of tertiary injectants. The tax credit is contingent upon professional certification, in advance, that the EOR project is capable of producing more than an insignificant increase in ultimate recovery. Because the goal of the incentive is to make the application of EOR techniques economic at lower oil prices, where project economics are most impacted, the incentive is gradually phased out at oil prices above \$28/B. For every \$1/B that the average benchmark price for the preceding year exceeds \$28/B, the incentive is reduced by 2.5 percentage points for the subsequent year, so that a complete

phasing out of the incentive would occur at an oil price of \$34/B. The study also accounts for the current state tax structure in New Mexico, including a tax incentive for EOR and ASR projects. This incentive reduces the severance tax on production from qualified EOR and ASR projects from 3.75% to 1.875% if oil prices are less than \$28/B. It is assumed that all analyzed projects qualify for the incentive.

3. Cost and Price Data

An informal survey of industry representatives has determined that the NPC costing algorithms for investments are still valid for the present study, provided that prices analyzed are consistent with the year of the cost data. The only exception to the use of the NPC's cost algorithms is the cost of enhanced recovery injectants delivered to the field. The NPC assumed a CO₂ purchase price in the Permian Basin of West Texas and Eastern New Mexico of \$1.25 per thousand standard cubic feet (Mcf) at an oil price of \$30/B. The NPC adjusted for changes in oil price using the equation:

$$\text{CO}_2 \text{ Price (\$/Mcf)} = \$0.50 + \$0.025 \times \text{Oil Price (\$/B)}.^4$$

However, the base price and adjustment equation were established at higher oil prices and before the completion of major CO₂ pipelines or significant CO₂ deliveries to the region. An informal poll of pipeline and field operators suggests that the CO₂ prices at present and into the near future will be lower (relative to oil prices) than the NPC had assumed. The CO₂ purchase price in West Texas has been adjusted for changes in oil price using the equation:

$$\text{CO}_2 \text{ Price (\$/Mcf)} = \$0.50 + \$0.02 \times \text{Oil Price (\$/B)}.$$

This equation results in a CO₂ price of \$0.90/Mcf at the \$20/B oil price. CO₂ prices in other regions of the state are assumed to be double the West Texas price, based on previous NPC surveys.

Chemical injectant costs have also been adjusted based on a survey of operators and suppliers. Polymer costs, assumed to be \$1.60 per active pound by the NPC, have been reduced to \$1.33 per active pound based on the current cost of low temperature, low salinity polymers. The cost is increased where oil and reservoir properties dictate the use of high molecular weight polymers. Surfactant costs used by

⁴ National Petroleum Council, *Enhanced Oil Recovery*, Washington, DC, 1984.

the NPC were based on a primary surfactant cost of \$0.32 per active pound and a secondary surfactant cost of \$0.44 per active pound. The surfactant slug cost based on these components was \$7.00/B. Prices paid by operators in recent field tests show this cost to be too low. Survey information shows that primary surfactant costs are higher (\$0.63/active pound), resulting in a \$10.17/B surfactant slug cost at a \$30/B oil price.⁵ Chemical costs have been adjusted for oil price changes as had been done in the NPC analysis, based on the energy component of the chemicals for different oil prices.

4. Benefits Estimation

The NPC did not calculate all of the individual items used in the present study's estimation of benefits. Special algorithms have been developed to estimate the number of jobs created, wages paid, and personal income taxes collected based on other elements already contained in the economic model. These algorithms are discussed further in Section F of this chapter.

5. Project Timing

The NPC's national perspective permitted a timing algorithm based principally on the assumption that the most economically attractive reservoirs would be developed first, given some broad constraints. A more detailed timing approach for both EOR and ASR was used in the present study. Timing for the application of EOR recovery techniques is estimated in two steps. First, project starting dates for EOR that are documented in the literature are used to time recently started operations. Second, when project start up dates are not available, the year that average well abandonment will occur for each reservoir under conventional recovery is estimated. This abandonment date is based on the projected rate of decline and economic limit of conventional recovery for each reservoir. EOR recovery is then phased in to occur reservoir-wide, at the latest, by three years following the estimated abandonment date. Projects that are not timed in by this data are assumed abandoned and are excluded from the analysis. The timing of ASR reserves development and production was accomplished using the Crude Oil Policy Model (COPM) because the TORIS timing model was not suited for ASR for technical reasons. COPM simulates the development of an aggregate resource as a function of project economics, while simultaneously accounting for abandonment of the undeveloped portion of the resource and technology transfer constraints. Inputs

⁵ Ray, et al., *Potential Crude Oil Production from Enhanced Oil Recovery*, U.S. Department of Energy, Bartlesville Project Office, 1986.

to COPM include the total resource potential, development and production costs, technology availability dates, technology penetration rates, abandonments rates, and reserves development rates. Outputs from the model include annual production, reserve additions, abandonments, development costs, operating costs, wages, and taxes. Reserves estimates were supplied by TORIS.

Total reserves were disaggregated into two categories, reserves available with implemented technology and incremental reserves available through the application of advanced technology. Appropriate model parameters were selected for each of these resource categories. The technology availability dates were set to 1993 for implemented technology and 2000 for advanced technology. Technology penetration rates were set at 75% in 12 years for implemented technology and 75% in 8 years for advanced technology, with the advanced technology case representing an aggressive technology transfer effort. Abandonment rates for both implemented and advanced technology were set to 3% of the undeveloped resource per year prior to technology availability and 1.5% per year after technology becomes available. Reserves development rates corresponded to typical field development profiles.

F. ESTIMATION OF BENEFITS, COSTS, AND ECONOMIC IMPACTS

The NPC study analyzed each reservoir from the perspective of the operator deciding whether to implement advanced oil recovery processes. The present study does the same in evaluating the economic viability of each reservoir. Thus, the benefits and costs to the operators are explicitly captured in the net cash flow calculations of individual projects. Under each of the various cases analyzed, projects yielding a net present value greater than the hurdle rate are assumed to be developed. This assumption is the basis for the projection of potential incremental production and reserves.

The incremental benefits and costs of EOR and ASR are estimated and reported on an annual as well as a cumulative basis. As previously discussed, reservoir timing is based on the estimated abandonment of the resource due to production decline, except for major reservoirs in which activity suggests earlier project start dates. Projects are phased in over a 5- to 10-year period to achieve full project development before this abandonment would occur. Annual estimates of benefits are based on the total economic resource produced in a given year. These annual values are reported for a twenty-seven year period, 1993 to 2020. Cumulative benefits include the sum of the annual benefits plus any additional benefits that would accrue after 2020. The total length of time for the life of all projects varies considerably depending on the process, oil price, and tax treatment. The vast majority of cumulative

production and benefits occur in the twenty-seven year period of focus in this study. The additional benefits that occur after 2020 are generally small relative to the total benefit, but important to the overall aggregate analysis.

1. Benefits to State and Local Treasuries

The benefits to New Mexico state and local treasuries from advanced oil recovery processes are the additional tax revenues attributable to implementation of the projects. These taxes include production taxes, sales tax on equipment and material purchases and corporate and personal income taxes on wages paid and operator profits. Evaluating these benefits under the current tax structure involves estimating the sum of these revenues as they apply to the development of the projects and the activities associated with the incremental production from improved recovery projects.

2. Direct State Economic Effects

The effect on the state's treasury is only one segment of the benefits of advanced oil recovery processes. The citizens of New Mexico also gain from the increased economic activity. Only the direct effects of the incremental activity are included, not the economic "multiplier" or indirect "ripple effect" activities (e.g., pipeline construction, retail sales, etc.). The direct impact on the state's economy is defined as the sum of net revenues to the state and local treasuries (as presented above); royalties to individuals, corporations, and the state; expendable (intangible) drilling materials and services; and operating costs excluding injectant purchases. It is assumed that these funds flow predominantly to the state of New Mexico and its citizens.

Excluded from this state economic activity definition are cashflows that generally benefit citizens of other states in larger proportion than they benefit the citizens of New Mexico. These include costs for tubular steel products installed in wells, injection and production equipment, purchased tertiary injectants, and other oil field materials typically manufactured out-of-state. To the extent that these goods are marketed by distributors in New Mexico, the direct benefits of these "retail pass-through" to the state are omitted from the estimates of direct state economic activity. Similarly, while it is recognized that a portion of tertiary injectants, especially chemicals, may originate in New Mexico (generating royalties, employment, taxes, and/or other economic activity), estimating these quantities is outside the scope of the present study. Other excluded items include Federal taxes, corporate debt service, and return on capital.

While the citizens of New Mexico obviously benefit from these excluded elements as U.S. citizens, or as employees and stockholders of companies providing services, they share them with a much larger population. Thus, the definition used for direct economic effects understates the actual benefits to the state of New Mexico and its citizens.

The additional jobs, wages, and benefits created by improved oil recovery are also estimated. Labor costs (wages and fringe benefits) are calculated by isolating the labor component of all major cost elements. Table III-7 summarizes the major cost elements and their respective labor and material components. Labor costs are converted into estimated numbers of jobs by dividing total wages by the average oil field wages (including benefits) reported by the U.S. Department of Labor.⁶ Sales tax revenues are calculated based on the materials component of these costs, assuming purchasers would pay the appropriate state tax on these goods.

3. National Effects

The Federal government benefits substantially, both directly and indirectly, from increased recovery of the New Mexico oil resource. Direct Federal taxes total 5% to 20% of the value of each barrel of oil recovered. Each additional barrel of New Mexico oil production can replace a barrel of imported oil. Therefore, each dollar used to purchase the incremental barrels of oil that would otherwise pay for imports is, potentially, a dollar reduction in the trade deficit.⁷ To estimate the direct effects on import replacement (i.e., excluding multiplier effects), the gross revenue from the additional production is used. This measure of gross revenues incorporates direct in-state economic activity and excludes elements discussed in the section above. In this sense, the estimated increase in import replacement represents a more complete measurement of direct economic impacts, excluding multiplier effects. In addition, corporate and individual Federal income taxes are estimated to assess the direct effects of incremental oil recovery in New Mexico on the Federal treasury.

⁶ U.S. Department of Labor, Bureau of Labor Statistics, 1985.

⁷ Although constraints caused by limited financial or personnel resources may result in delayed national benefits due to short-term deferral of projects in other states, the aggregate benefits to the nation should be achieved as all economic projects will ultimately be developed.

Table III-7

Labor and Materials as Percentage of Total Cost in EOR Projects

<u>Investments</u>	<u>% Labor</u>	<u>% Materials</u>	<u>% Other</u>
Drilling Wells	18	55	27
Work-overs	15	63	22
Equipping Wells	10	50	40
Pipe Installation	10	50	40
Plant Installation	16	46	38
<u>Expenses</u>			
Field Operations	33	58	9
Plant Operations	38	57	5
Production Treating	0	100	0
Overhead	100	0	0

Sources:

Investments

- Drilling and Work-overs
 - NPC, 1984
 - EIA, 1984
 - Professor Neil J. Dikeman, University of Oklahoma, 1986
- Equipping Wells
 - Industry estimate
- Pipe Installation
 - Industry estimate
- Plant Installation
 - Modern Cost Engineering Technologies, Herbert Popper, page 82-83

Expenses

- Field Operations
 - EIA, 1984
- Plant Operations
 - NPC, 1984
 - EIA, 1984 (power and chemicals)
- Production Treating
 - By definition
- Overhead
 - NPC, 1984

G. LIMITATIONS TO THE ANALYTICAL APPROACH

The approach followed by this study has limitations that should be considered in utilizing its results. Some of these follow from the adoption of the NPC methodology; others result from the need to limit the scope of the present effort. It is also important to note that the results of this analysis are not forecasts of future oil recovery; they are estimates of the recovery potential of selected EOR and ASR processes.

The NPC approach, while the most credible and flexible methodology available, has certain distinct limitations. One problem is the reliance on averaged reservoir and fluid properties. Oil reservoirs are actually highly heterogeneous, with erratic properties throughout the field. The use of averaged properties belies the fact that portions of an individual reservoir could be highly attractive as an advanced technology oil recovery prospect even if the whole reservoir, on average, is not economic. Given the present methodology, reservoirs must be economically accepted or rejected as whole units, unless advanced geoscientific knowledge allows the reservoir to be evaluated in segments. The methodologies of both the present study and the NPC assume that the least favorable 20 percent of any reservoir would not be developed under EOR or ASR operations.

A second limitation is the use of regional costing algorithms. Although developed from the best available data and explicitly adjusted for variations in energy costs and specific reservoir characteristics, they do not reflect site-specific cost variations applicable to specific operators. Thus, this study does not necessarily use the actual costs of individual projects. To the extent that the average costs used understate or overstate the true project costs, the actual results will be higher or lower than the analysis estimates.

A third limitation is the use of simplified process performance models. While the models used in this project are extensively calibrated, they are designed to analyze large numbers of individual reservoirs quickly and simultaneously. Therefore, while they incorporate all the relevant reservoir engineering concepts, they are relatively simplified and generalized. In this simplified state, the models cannot be as accurate as highly detailed reservoir simulators in which very specific reservoir features and process designs may be evaluated (such as assessments used in the actual design of specific projects). The present study assumes these models are appropriate for aggregate analyses but not necessarily for individual reservoirs. Further, these models are explicitly designed to estimate only incremental recovery resulting from advanced oil recovery processes after completion of conventional production operations.

Laboratory and limited field data suggest that application of some of these techniques before the economic limit of conventional recovery could yield more than the sum of conventional and advanced oil recovery, but this is not reflected in the models.

An additional limitation arises from the methodological convention of "constant price" analysis. The use of this convention is consistent with the NPC's original nationwide study, conducted during a period of relatively stable, rising oil prices, and differentiates the effect of oil price from other effects. It can, however, cause a distortion, especially in times of declining or radically changing oil prices. The "hidden" assumption of this convention is that each of the respective oil prices analyzed must be attained by the time (and be expected to continue at that level after) the decision to commit specific reservoirs to enhanced recovery or advanced mobile oil recovery operations is made. This decision is generally made several years before the reservoir's final, actual economic limit is reached under conventional technology. To the extent this condition is not met, existing wells reaching their economic limits at lower prices will be shut-in and abandoned, making them unavailable for use in advanced oil recovery projects, as assumed. The economic model assumes that all existing wells will be utilized in future operations, although older wells may require workovers. Should "premature" abandonments occur, these wells would need to be redrilled, resulting in additional incremental investment not included in this analysis (although necessary workovers are included in the assumed cost). Redrilling would result in substantially increased costs and would thus increase the minimum oil price at which advanced oil recovery processes are profitable for certain reservoirs. The net effect of this analytic convention could overstate the economic reserves and production and the corresponding economic benefits. Under these conditions, the "constant price" convention introduces an optimistic bias to the present analysis.

Finally, the analysis follows the NPC approach, which assumed that project operation would be conducted by an integrated major oil company. This approach, in most cases, presents the least favorable corporate tax treatment for investments and revenues from advanced oil recovery projects and assumes a relatively high overhead on operations. Independent producers operate with a different corporate structure, tax situation, and overhead rate. Because most costs used in this analysis are not affected by total project size and some non-integrated operators would enjoy more favorable tax treatment, smaller independent producers should receive the same benefit as a major oil company from application of advanced oil recovery processes, possibly even at lower oil prices than projected in this evaluation.

None of the above limitations invalidate the results of this analysis. Given the uncertainty of the size and combinations of the optimistic and pessimistic biases introduced by these limitations, it is assumed that the approach is valid and the resulting projections are reasonable. To avoid misinterpretation of particular reservoirs, and to respect the confidence in which some project and reservoir data were obtained, no reservoir specific date is provided in the reports generated from this analysis. However, in cases where the results seemed unusual, the modeling specifications for specific reservoirs were examined in-depth to ensure the validity of the results.

IV. INCREASED RECOVERY FROM THE KNOWN REMAINING OIL RESOURCE IN NEW MEXICO UNDER IMPLEMENTED TECHNOLOGY

A. INTRODUCTION

This chapter discusses the post-conventional reserve additions and potential economic impacts attributable to the application of currently available (implemented technology) oil recovery methods in analyzed New Mexico reservoirs. Chapter V discusses the incremental reserves and benefits under advanced technology methods attainable through RD&D. The TORIS reservoirs analyzed in this study are individually modeled to evaluate their potential for incremental production and reserves by tertiary and advanced secondary recovery techniques under a variety of oil prices and economic conditions. Some key technical assumptions and considerations regarding the analysis in this report are:

- The incremental production and reserves refers to future recovery estimated for the analyzed EOR and ASR techniques. Such production and reserves are above and beyond the recovery attainable by primary and secondary recovery techniques.
- Both light oil (API > 20 degree) and heavy oil (API ≤ 20 degree) resources are considered in this analysis.
- All EOR and ASR recovery potential evaluated in this report reflect future new projects only, and they do not include incremental reserves from existing (ongoing) EOR and ASR projects. However, the expansion to the ongoing projects, if technically and economically feasible, are evaluated as part of future new projects in this report.

All reservoirs are screened for technical criteria and are analyzed in detail using the process performance and economic models described in Chapter III. The results are based on the evaluation of 94 reservoirs in New Mexico for their EOR and ASR potential. The results of this analysis were not extrapolated to the rest of the reservoirs making up the New Mexico resource.

B. RECOVERY OF THE REMAINING IMMOBILE OIL RESOURCE

1. Production and Reserves

Over the price range analyzed, currently available EOR processes could stimulate from 19 million to 130 million barrels of incremental reserves. This potential represents up to an 18% increase in the state's 1991 proved reserves (721 million barrels). At oil prices of \$20 per barrel (/B) or less, the potential incremental reserves could be relatively small. However, as the oil price rises above \$20/B, EOR

processes could become increasingly prolific, and substantial incremental reserves could become economically attainable (Figure IV-1A and Table IV-1). The 36 million barrels of potential EOR reserves at \$20/B could increase by an estimated 80 million barrels with a \$4/B increase in the oil price. As oil prices increase to \$28/B, another 11 million barrels of incremental reserves could be generated for a total of 127 million barrels. At \$36/B, EOR techniques could ultimately produce 130 million barrels of incremental reserves.

Among the EOR processes considered in this analysis, only the carbon dioxide (CO₂) miscible process could stimulate incremental reserves at all oil prices (Figure IV-1A and Table IV-1). The relatively inexpensive supply of CO₂ and the character of the large carbonate reservoirs in Eastern New Mexico give this technique an economic advantage over other EOR processes at lower oil prices. At an oil price of \$16/B, all the potential incremental reserves would be attributable to CO₂ miscible floods implemented outside of the Permian Basin. At \$24/B, 60% of the 80 million barrel increase in incremental reserves from EOR could be attributed to miscible floods using a Permian Basin CO₂ source. Even as additional Permian Basin CO₂ projects are implemented, projects utilizing other CO₂ sources could account for 40% of the incremental reserves from EOR. High chemical costs and relatively small volumes of heavy oil (reserves with API $\leq$ 20 degrees) preclude the wide-scale application of chemical and thermal flooding projects in the analyzed New Mexico reservoirs under implemented technology conditions.

Table IV-1 shows the number of EOR projects that could be initiated at different oil prices. Of the analyzed New Mexico reservoirs, only 13% would be economic to develop with current EOR technology at oil prices of \$36/B or below. CO₂-miscible floods could account for all of the EOR projects considered economic in the price range evaluated, and at oil prices of \$16/B, CO₂ miscible floods outside the Permian Basin could account for all economic New Mexico EOR projects. In most cases, the economic projects are in the large reservoirs, but size alone is not a major determinant of EOR economics.

The annual incremental production resulting from implemented technology EOR is determined by phasing in economic projects based on the demonstrated economic limit of conventional production, as well as other constraints, as discussed in Chapter III. Figure IV-1B shows the expected annual production from EOR processes for oil prices of \$16/B and \$32/B per barrel. At \$16/B, nearly 40% of the annual production from the potential incremental reserves could occur by the year 2000. Another 40% of the total production could occur from the years 2001 to 2005. After peaking in the year 2002 at 1.7 million barrels per year, annual production could decline for the next 15 years. At \$32/B, over 12% of the potential annual production from EOR reserves could occur by the year 2000. An additional 14% of the

Table IV-1

Incremental Reserves and Projects from CO₂-Miscible EOR* Implemented Technology

Oil Price (\$/B)	Incremental Reserves (Million Barrels)	Project Count
\$16	19	3
\$20	36	5
\$24	116	10
\$28	127	12
\$32	127	12
\$36	130	12

* The analyzed New Mexico reservoirs did not exhibit chemical or thermal EOR potential using implemented technology.

potential reserves could be produced between the years 2001 and 2005. The peak annual production rate at \$32/B (3.6 million barrels per year in the year 2002) represents a 5% increase in New Mexico's 1991 production levels.

2. Increases in State and Local Revenues

EOR production could also increase state and local revenues by stimulating new sources of production taxes and sales taxes on purchased materials used in the projects and by increasing corporate and personal income taxes. The estimated revenues would be directly generated from oil production or operations in the analyzed New Mexico reservoirs. State and local revenues generated over the life of the EOR projects vary considerably with oil prices, as shown in Figure IV-2. A significant portion of these revenues could result from production taxes. At \$20/B, nearly \$73 million in incremental revenues could be generated, with production taxes contributing over 63% of the total. A \$24/B oil price could yield production tax revenues of \$177 million with an additional \$96 million in corporate income, personal income, and sales tax receipts. At \$28/B, additional revenues could reach as high as \$353 million. At the highest price case of \$36/B, \$548 million of additional state and local revenues could be generated by implemented technology EOR activities.

Figure IV-1

Reserves and Production Response from EOR Techniques

Implemented Technology

A) Incremental Reserves from CO₂-Miscible EOR*

* There was no economic thermal or chemical reserves potential in analyzed reservoirs.

B) Annual Production from CO₂-Miscible EOR

Figure IV-2

Direct State and Local Revenues from EOR Production Implemented Technology

3. Effects on the State Economy

In addition to the incremental state and local revenues, implemented technology EOR would benefit New Mexico by increasing economic activity and by creating or maintaining jobs in the industry. The effects of EOR on the state economy are estimated conservatively: (1) only direct effects are included (i.e., no economic multiplier due to secondary effects); and (2) the direct effects are limited to benefits believed to accrue predominantly to the state of New Mexico and its citizens. Only intangible drilling costs, royalties, state and local taxes (as defined in the previous section), and operating costs, exclusive of purchased injectant, are included in the calculation of state economic activity. Tubular steel products, injection and production equipment, purchased EOR injectant, corporate return on capital, and Federal taxes are all excluded from this definition of state economic activities. Royalties may be overstated to the extent that they are paid to the Federal government (i.e., from production on Federal lands). While the excluded elements undoubtedly aid New Mexico's citizens to some degree, a substantial portion of the benefits will be enjoyed by citizens of other states. However, to the extent that local manufacture or retail sales of these items provide economic benefits within New Mexico, injectants produced or manufactured in New Mexico are employed, or economic "multipliers" occur, the calculated economic effects are understated.

Figure IV-3 displays the total direct economic gains for the state over the oil price range analyzed. In all cases, operating costs could account for at least 58% of these economic effects; state taxes could represent between 15% and 19%; intangible investment could be about 2%; and royalties could constitute about 20% of the total. At oil prices of \$20/B and lower, the economic benefits to the state could be limited due to the very small EOR production at this price. At \$20/B, incremental benefits to the state economy could approach \$450 million. A substantial increase in economic activity could occur at oil prices above \$20/B; \$1.8 billion could be generated at \$24/B, a four-fold increase over the \$4/B price increment. At \$28/B, an additional \$400 million could be generated by EOR projects for a total of \$2.2 billion. At the highest oil price considered, \$36/B, an estimated \$2.8 billion of statewide direct economic activity could be stimulated by implemented technology EOR projects.

Successful EOR projects could create or maintain a significant number of jobs statewide, as shown in Figure IV-4. At an oil price of \$16/B, an average of 65 jobs per year could be created or maintained through the year 2000. Over the following 10 years, an average of nearly 35 jobs could be created or maintained annually. At \$32/B, there could be significant increases in job potential, with an average of nearly 205 jobs created or maintained annually through the year 2000. After that, an average of over 194 jobs per year could be created or maintained by EOR projects until the year 2010.

4. Effects on the National Economy and Budget

Increased oil recovery from EOR in New Mexico could benefit the nation as a whole. National benefits could accrue in several ways: replacement of oil imports, increased Federal corporate and personal income tax revenues, and a reduced trade deficit. The addition of as many as 130 million barrels of incremental reserves in New Mexico could expand the nation's proved reserve base. Since an additional barrel of domestic oil production replaces a barrel of imported oil, the nation's energy security could be enhanced through the implementation of EOR in New Mexico.

EOR activity in New Mexico could contribute to the Federal treasury through personal and corporate income taxes. As shown in Figure IV-5A, increases in Federal revenues attributable to EOR could range from \$8 million at \$16/B to \$515 million at \$36/B over the life of the projects. At the more moderate oil prices of \$24/B and \$28/B, \$118 million and \$212 million could be stimulated by EOR projects, respectively. Corporate income taxes could account for between 25% and 89% of this total, depending on and generally increasing with the oil price, and personal income taxes could make up the remainder.

Figure IV-3

Direct State Economic Activity from EOR Production* Implemented Technology

* To the extent that royalties go to the Federal government (i.e. fields on Federal lands), royalties as a portion of state economic activity may be overstated

Figure IV-4

Jobs and Wages from EOR Production Implemented Technology

As imports are replaced, the trade deficit could be reduced by the direct value of the avoided imports (reserves multiplied by the effective wellhead price). Money, formerly paid to oil exporting countries, could instead circulate within the U.S. economy. The imports avoided through EOR production in New Mexico could range from \$313 million (at \$16/B) to \$4.7 billion (at \$36/B) **over** the life of the projects. The largest rise could occur as the oil price increases from \$20/B to \$24/B; avoided imports could increase by over \$2.0 billion, nearly quadrupling over the price increment (Figure IV-5B).

C. RECOVERY OF THE REMAINING MOBILE OIL RESOURCE

This section will discuss the application of currently available ASR processes in analyzed reservoirs throughout the state. Enhanced oil recovery and advanced secondary recovery technologies, have been addressed separately to illustrate the potential benefits of each. However, since the resource target of these two technologies is different, either or both could be implemented in any reservoir, and the results could be independent and additive. Given the potential synergies in the simultaneous application of EOR and ASR technologies, reserve additions and economic benefits of applying both could be even greater than estimated by summing the two independent results.

1. Production and Reserves

Depending on the oil price, ASR techniques applied in the analyzed New Mexico reservoirs could stimulate between 392 million and 537 million barrels of incremental reserves. ASR techniques are less costly to implement than EOR recovery processes, and therefore incremental reserves from ASR are less sensitive to changes in the oil price. As shown in Table IV-2A, at the lowest oil price analyzed (\$16/B), over 391 million additional barrels of incremental reserves could be recovered. At \$20/B, incremental ASR could amount to nearly 395 million barrels, over 73% of the oil economically producible by these techniques even at \$36/B. At oil prices of \$24/B and \$28/B, 467 million and 513 million barrels of incremental reserves, respectively, could be produced by ASR.

This analysis evaluates three categories of ASR processes: polymer flooding and profile modification, infill drilling, and combinations of infill drilling with polymer flooding or profile modification (combination processes). As shown in Figure IV-6A and Table IV-2A, infill drilling, both by itself and in combination with other processes, could play a predominant role in ASR, accounting for most of the incremental reserves at all oil prices. At an oil price of \$16/B, the combination processes could contribute 170 million barrels of incremental reserves, while infill drilling could contribute over 200

Figure IV-5

National Impact of EOR Production

Implemented Technology

A) Direct Federal Revenues

B) Imports Avoided*

* To the extent that 1 barrel of domestic oil replaces 1 barrel of imported oil, imports avoided measures the reduction in the foreign trade deficit.

million barrels of incremental reserves; the percentage of total ASR potential stemming from infill drilling, either alone or in combination with polymer flooding or profile modification, could be greater than 95% of the total potential at the given price. As oil prices increase, infill drilling by itself and the combination processes could make roughly equal contributions. At \$24/B, infill drilling alone could contribute over 44% of the 467 million barrels of total incremental reserves, close to the 53% contribution by the combination processes. At \$28/B and \$32/B, both infill drilling by itself and the combination processes could make nearly equal contributions (roughly 45%) to the total reserves potential. At the highest oil price analyzed, \$36/B, infill drilling by itself could generate 50% of the 537 million barrels of incremental reserves with the combination processes contributing over 47%.

Polymer flooding and profile modification, applied alone, could have limited potential in New Mexico, contributing only 16 million barrels to total reserves across all oil prices considered in this analysis. The reason that reserves from these projects do not rise with the oil price is that these processes compete with the more prolific infill drilling-related techniques. In this analysis, only one of the analyzed processes is implemented in each reservoir. As the oil price rises, the more expensive, but more prolific, infill drilling and combination projects are increasingly implemented, while the less prolific techniques are bypassed.

Table IV-2B shows the number of projects expected to be economic at each price for each recovery method. At higher oil prices, the number of infill drilling projects could be consistently higher than polymer flooding, profile modification, or combination projects. At \$24/B, infill drilling by itself could account for half of the ASR projects being implemented. At oil prices of \$28/B and \$32/B, these projects could account for approximately 62% of the total ASR projects.

Figure IV-6B displays the expected annual production from all ASR processes for oil prices of \$16/B and \$32/B. ASR projects are undertaken as reservoirs reach their economic limit. In this study, ASR projects are assigned initiation dates as a function of rig availability and technology transfer; projects are therefore phased in over time. As a result, some fields will be abandoned before ASR is implemented. This abandonment, which is reflected in annual production, is on the order of 24% of the potential resource at \$32/B. At \$16/B, nearly 22% of the potential ASR reserves could be produced in the next twenty years. Annual production could average only half a million barrels per year until the year 2000. Between the years 2000 and 2010, however, production from ASR reserves could average 7.3 million barrels per year, over 10% of New Mexico's 1991 production rate (70.4 million barrels per year). Production from ASR at an oil price of \$16/B could peak in the years 2015-2016 at 12.5 million barrels

Table IV-2A

**Incremental Reserves from ASR by Process
Implemented Technology
(Million Barrels)**

Oil Price (\$/B)	Polymer Flooding and Profile Modification	Infill Drilling	Infill Drilling and Polymer Flooding or Profile Modification	Total
\$16	16	206	170	392
\$20	16	141	238	395
\$24	16	204	247	467
\$28	16	245	252	513
\$32	16	247	251	514
\$36	16	269	252	537

Table IV-2B

**Estimated Number of Economic ASR Projects by Process
Implemented Technology
(Project Counts)**

Oil Price (\$/B)	Polymer Flooding and Profile Modification	Infill Drilling	Infill Drilling and Polymer Flooding or Profile Modification	Total
\$16	2	8	6	16
\$20	2	7	7	16
\$24	2	10	8	20
\$28	1	15	8	24
\$32	2	16	8	26
\$36	1	18	8	27

Figure IV-6

Reserves and Production Response from ASR Techniques

Implemented Technology

A) Incremental Reserves by ASR Process

B) Annual Production from ASR Reserves

per year. At \$32/B, similar trends in production occur. Over 21% of the annual production from potential ASR reserves could occur by the year 2010. Production rates from the year 2000 to 2010 could average nearly 9.6 million barrels per year, over 13% of 1991 production rates. As at \$32/B, annual production could peak in the years 2015-2016 at 16.4 million barrels per year.

2. Increases in State and Local Revenues

Figure IV-7 shows the expected growth in direct state revenues from ASR production and the proportional contributions of production taxes, sales taxes, and corporate and personal income taxes to the total. Production tax receipts could account for the largest portion of total state revenues from ASR over all prices considered. ASR activities could stimulate \$500 million in production taxes for the state at \$20/B, 57% of the \$870 million in additional state and local tax revenues. At \$28/B, \$1.5 billion could be generated for the state through ASR activities, 59% from production taxes.

3. Effects on the State Economy

Figure IV-8 displays the total state economic activity associated with potential ASR production. Total state economic activity from implemented technology ASR could range from \$3.2 billion at \$16/B to \$10 billion at \$36/B. At intermediate oil prices, state economic activity could total \$5.6 billion at \$24/B and \$7.6 billion at \$28/B. State taxes, operating costs, and royalties could all make roughly equal contributions to state economic activity (between 21% and 26%). Intangible investment generally could account for a slightly higher portion (between 27% and 30%) across all the oil prices considered.

The implementation of ASR techniques could significantly contribute to employment in the state of New Mexico. Figure IV-9 displays the annual number of jobs that could be created or maintained by ASR projects. At \$16/B, an average of nearly 105 jobs could be created or maintained annually through the year 2010 by activities associated with ASR production. In the ten years following (2011 to 2020), over 270 jobs per year could be created or maintained, peaking around the year 2016. At an oil price of \$32/B, there could be a substantial increase in the number of jobs created or maintained. On average 210 jobs could be created or maintained annually by the year 2010. From 2011 to 2020, an average of 550 jobs per year could be created or maintained by implemented technology ASR activities.

Figure IV-7

Direct State and Local Revenues from ASR Production Implemented Technology

4. Effects on the National Economy and Budget

Figure IV-10 shows the national benefits of ASR production in New Mexico. Federal revenues from ASR production could range from about \$1 billion to more than \$3 billion over the oil price range analyzed. Figure IV-10A shows that nearly all of these revenues could stem from corporate income taxes. At \$20/B, \$1.4 billion in Federal revenues could be generated. With each \$4/B increase to \$24/B and \$28/B, Federal revenues could increase by approximately \$400 million, reaching \$2.2 billion at a \$28/B oil price.

Increased domestic production could replace imports and reduce the trade deficit by the direct value of the avoided imports. Imports avoided due to implemented technology ASR production in New Mexico could total between \$6.2 and \$19 billion over the oil price range analyzed (Figure IV-10B). The largest rise occurs as price increases from \$20/B to \$24/B; imports avoided could increase by over 41% to \$11 billion from \$7.9 billion. Otherwise, as price increases, avoided imports could increase by between 14% and 28%, for each \$4/B increase in price, reaching \$19 billion at \$36/B.

Figure IV-8

Direct State Economic Activity from ASR Production* Implemented Technology

* To the extent that royalties go to the Federal government (i.e. fields on Federal lands), royalties as a portion of state economic activity may be overstated.

Figure IV-9

Jobs and Wages from ASR Production Implemented Technology

Figure IV-10

National Impact of ASR Production

Implemented Technology

A) Direct Federal Revenues

B) Imports Avoided*

* To the extent that 1 barrel of domestic oil replaces 1 barrel of imported oil, imports avoided measures the reduction in the foreign trade deficit.

D. CONCLUSIONS

The existing level of EOR and ASR technologies could make significant contributions to the reserve base and the New Mexico and national economies, as well as to domestic energy security. At a \$24/B oil price, EOR processes could add 116 million barrels to New Mexico reserves while ASR techniques could add nearly 470 million barrels. The application of current EOR and ASR technologies, in concert, could potentially add over 580 million barrels of incremental reserves at this price, nearly equalling New Mexico's current proved reserves. As discussed in the next chapter, improved geoscientific understanding of reservoirs and enhanced process performance could increase these benefits if the required research can be cost effectively completed and transferred to the producers.

The state of New Mexico and its citizens stand to gain significantly from the increased production resulting from the implementation of currently available EOR and ASR techniques. Production increases could generate \$940 million to over \$1.9 billion in additional state and local revenues over the life the analyzed projects assuming oil prices of \$20/B to \$28/B. Total state economic activity could be boosted by \$4.2 billion to nearly \$10 billion. Jobs could be created or maintained, and state economic activity could increase. The national economy could benefit through decreased oil imports, reductions in the trade deficit, and increased Federal corporate and personal income tax revenues. Maximizing recovery of the known oil resource in New Mexico should therefore be an important goal for state and Federal policymakers. While these benefits could be available using currently available technology, the true potential could not be realized without an aggressive program of technology transfer. The estimated potential assumes wide application of these technologies. A collaborative technology transfer effort between the public and private sectors is critical to the attainment of these estimated benefits.

As shown in Figure IV-11, the oil that will remain in the analyzed reservoirs after production by both current operations and by wide-scale application of currently available EOR and ASR processes constitutes an important resource target for advanced recovery technologies. Of the 5.8 billion barrels of immobile oil resource analyzed in this study, implemented technology EOR practices as defined in this report could produce an estimated 130 million barrels at an oil price of \$36/B, leaving 5.7 billion barrels of remaining immobile oil in these reservoirs. Of the 2.2 billion barrels of unrecovered mobile oil in the reservoirs analyzed, implemented technology practices could produce almost 540 million barrels at \$36/B, leaving nearly 2.1 billion barrels of oil in these reservoirs. The large size of the remaining resource clearly warrants a focused RD&D program that will test and speed the implementation of advanced technology to capture additional oil reserves.

Figure IV-11

New Mexico Remaining Oil Resource After Implemented Technology Recovery

V. BENEFITS OF INCREASED RECOVERY FROM THE KNOWN REMAINING OIL RESOURCE IN NEW MEXICO WITH TECHNOLOGY ADVANCES

A. INTRODUCTION

While currently available enhanced oil recovery (EOR) and advanced secondary recovery (ASR) techniques could contribute substantially to the New Mexico reserve base, technological advances in these processes resulting from a concerted RD&D effort would have far more dramatic effects on the state's oil production and reserves. Development and wide-scale application of advanced methods could result in the recovery of a much greater portion of the remaining mobile and immobile oil resources in the state.

The present analysis evaluates the impact of advanced technology on oil recovery and the associated economic benefits. Evaluations of advanced technology EOR and ASR recovery potential in the state of New Mexico are presented separately. Given that the modeled advances in technology are conservatively defined, improvements in recovery processes resulting from research and development not envisioned in this report could add substantially to the estimated reserve potentials. However, well abandonments could limit access to the resource and increase project costs if EOR and ASR are not applied before conventional production ceases. Immediate actions are therefore necessary to realize the economic benefits of these advanced processes.

B. RECOVERY OF THE REMAINING IMMOBILE OIL RESOURCE

1. "Advanced" Technology Defined

Enhanced oil recovery processes, as currently applied, have severe limitations. Some current EOR techniques can only be applied in a limited number of reservoirs with properties which fall within a narrow range of suitable values (temperature, salinity, oil viscosity, etc.). The sweep efficiency of EOR processes is often relatively poor; only a small portion of the residual oil remaining in the previously waterflooded zone is contacted. Injectants are expensive, often approaching the value of the oil they are designed to recover, which places a burden on project economics. The National Petroleum Council (NPC) predicted gradual improvements in EOR performance and project economics as current processes are

improved and tested in the lab and field. These advanced processes are predicted to gain operator acceptance as the research and development efforts of oil companies, universities, geologic surveys, and the Federal government proceed and as field applications prove commercial viability. In this report, the IOGCC delayed the advanced technology availability date from the NPC's assumption of 1995 to the year 2000, to reflect the slower pace of RD&D activities in recent years caused by relatively low oil prices.

The major improvements in technology that are likely to impact enhanced oil recovery in New Mexico will be advances in chemical EOR applications. For advanced technology thermal recovery, the NPC modeled the effects of an improvement in the ability to inject steam at greater depths and into thinner, lower permeability reservoirs. For advanced technology chemical flooding, the NPC modeled the effects of increasing the salinity and temperature tolerance of injectants, thus enabling them to be applied in a larger number of reservoirs. This study also assumes that advances in chemical flood technology would result in improvements in injection rate, interfacial tension reduction, lower costs, and reduced chemical retention, thereby improving the recovery and economics of chemical projects. Additionally, the risk factors associated with current chemical and gas-miscible flooding (modeled as a reduction in the minimum rate of return or hurdle rate) are assumed to be substantially reduced by an RD&D effort.

2. Production and Reserves

With technology advances, EOR could stimulate a substantial amount of incremental reserves over the analyzed oil price range (\$16/B to \$36/B). Figure V-1A and Table V-1A show the comparison between the incremental reserves potentially generated through the application of implemented technology EOR processes and advanced technology EOR processes. The greatest increase in incremental reserves due to advanced technology would occur in the upper end of the analyzed price range, at oil prices of \$24/B and greater. At \$20/B and below, incremental reserves from advanced technology EOR would be about equal to those generated using currently available EOR techniques. Over the \$24/B to \$32/B price range, incremental reserves attributable to advanced technology EOR processes could be 7 million to 12 million barrels greater than those for current EOR processes at each respective oil price considered. At \$36/B, technology advances could add over 60 million barrels of incremental reserves, for a total of over 190 million barrels of potential reserves from EOR.

The potential incremental reserves contributed by each of the advanced technology EOR processes considered in this analysis are also shown in Figure V-1A. At oil prices of \$28/B and greater, advanced

chemical flooding could become a source of incremental reserves, accounting for around 5 million barrels. Under implemented technology, chemical flooding processes were not economic at any of the considered oil prices. Thermal recovery in New Mexico would remain uneconomic over the entire price range, despite advances in technology.

At all oil prices considered, CO₂-miscible flooding could remain the primary source of incremental reserves under advanced technology. At \$20/B, advances in CO₂-miscible flooding technology could add only one million barrels to the potential reserves generated under implemented technology. At prices of \$24/B and \$28/B, advances in EOR technology could stimulate 7 million and 11 million barrels of incremental reserves over implemented technology potential, respectively; total incremental reserves generated by EOR at these prices could total 123 to 138 million barrels. If oil prices were to reach \$36/B, historically high levels, technology advances in CO₂-miscible flooding could yield an increase of 58 million barrels of incremental reserves, approximately 30% of the total potential reserve additions at this price. At \$28/B, the 138 million barrels of total incremental reserves from EOR using advanced technology would be a 19% increase to New Mexico's 1991 proved reserves (721 million barrels).

The number of EOR projects for each process type is shown in Table V-1B. The comparison of the project count by process indicates the reasons for the increase in reserves under advanced technology conditions. Only one chemical flood could become economic at \$28/B, but it does not add significantly to the reserves base. The advances made in chemical flood technology could slightly increase the efficiency of the process and improve project economics. Technology advances in CO₂-miscible processes, however, primarily involve increased project efficiency. While no additional reservoirs could become economic to develop using CO₂-miscible flooding, incremental reserves potentially attributable to this process do increase with advances in technology.

Figure V-1B shows the expected annual EOR production for an oil price of \$32/B for both the implemented and advanced technology scenarios. At \$16/B, no difference is observed between the implemented and advanced technology EOR potential. At \$32/B, a large portion of the increases in annual production which are attributable to technology advances would occur within 10 years after these advances are introduced in the field (in the year 2000 and later). Under advanced technology, the peak production rate of 5.2 million barrels per year in the year 2002 would be 44% greater than the peak under implemented technology. This peak rate would be a 7% increase in the state's 1991 annual production rate (70.4 million barrels per year). As under implemented technology, over 50% of the production increases could occur after the year 2020.

Table V-1A

Incremental Reserves from EOR by Process*
Implemented Technology vs. Advanced Technology
(Million Barrels)

Oil Price (\$/B)	CO ₂ -Miscible		Chemical		Total	
	Implemented	Advanced**	Implemented	Advanced**	Implemented	Advanced**
\$16	19	19	0	0	19	19
\$20	36	37	0	0	36	37
\$24	116	123	0	0	116	123
\$28	127	133	0	5	127	138
\$32	127	135	0	5	127	139
\$36	130	188	0	5	130	192

- * Analyzed New Mexico reservoirs did not exhibit any thermal EOR potential.
- ** This is the total reserves with advanced technology -- implemented technology plus the increment due to technology advances.

Table V-1B

Estimated Number of Economic EOR Projects by Process*
Implemented Technology vs. Advanced Technology
(Project Counts)

Oil Price (\$/B)	CO ₂ -Miscible		Chemical		Total	
	Implemented	Advanced	Implemented	Advanced	Implemented	Advanced
\$16	3	3	0	0	3	3
\$20	5	5	0	0	5	5
\$24	10	10	0	0	10	10
\$28	12	12	0	1	12	13
\$32	12	12	0	1	12	13
\$36	12	12	0	1	12	13

- * Analyzed New Mexico reservoirs did not exhibit any thermal EOR potential.

Figure V-1

Reserves and Production Response to EOR

Implemented Technology vs. Advanced Technology

A) Incremental Reserves by EOR Process*

* There was no economic thermal reserves potential in analyzed reservoirs.

B) Annual Production from EOR at \$32/B

3. Effects on State Revenues and Economic Activity

At most of the oil prices considered in this analysis, the direct revenues to the state of New Mexico attributable to EOR could significantly increase with advanced technology (Figure V-2A). Similar to the implemented technology case, production taxes could account for between 65% and 75% of the state's total direct revenues with corporate income tax and sales tax receipts contributing most of the remainder at oil prices of \$24/B and higher. At \$24/B, advances in technology could increase state revenues by \$12 million over implemented technology for a total potential of \$285 million. At \$28/B, \$30 million in additional state revenues could be generated by advances in technology, leading to over \$380 million in total state and local revenues. At oil prices above \$28/B, the state tax incentive is no longer in effect and the revenue increases could be more substantial; \$765 million in total state and local revenues could be generated by EOR activities at \$36/B, 28% of which would be attributable to advances in technology.

Direct state economic activity generated by New Mexico EOR could also grow due to advances in technology. The economic benefits would be proportional to the gain in reserves. Figure V-2B displays the potential incremental direct economic benefits to the state for both the implemented and advanced technology cases. The distribution of total economic benefits among the contributing components in the advanced technology case is similar to the trend shown for implemented technology. At \$16/B and \$20/B, the incremental state economic gain due to advanced EOR technology is only slightly higher than that of the implemented technology case. A \$24/B oil price with advanced technology development could, however, increase state economic activity by over \$180 million for a total of nearly \$2.0 billion in additional economic activity. At \$28/B, technology advances could stimulate almost \$300 million in direct state-wide economic gain for a total potential of greater than \$2.5 billion. Clearly, the state of New Mexico could accrue substantial benefits from the development and application of advanced EOR technology.

Advanced technology could also have a direct impact on the state's employment. As in the implemented technology case, the development of advanced technology could create or maintain 196 jobs annually by the year 2000 at an oil price of \$32/B (not illustrated). As advances in technology are implemented in the state's reservoirs in the year 2000 and after, over 260 jobs per year could be created or maintained using advanced technology EOR between the years 2000 and 2010, 60 more than under implemented technology.

Figure V-2

State Impact of EOR Production

Implemented Technology vs. Advanced Technology

A) Direct State and Local Revenues

B) Direct State Economic Activity*

* To the extent that royalties go to the Federal government (i.e. fields on Federal lands), royalties as a portion of state economic activity may be overstated.

4. Effects on the National Economy and Budget

As discussed in Chapter IV, increased oil recovery in the state of New Mexico through EOR methods could significantly benefit the nation in the areas of enhanced energy security, import replacement, a reduced trade deficit, and expanded direct revenues to the Federal treasury. The potential benefits are even more pronounced with the development of advanced technology. At \$28/B, nearly 140 million barrels of crude oil could be added to proved reserves due to advanced EOR technology, 11 million barrels more than the incremental reserves estimated under the implemented case.

Under advanced technology, it is assumed that operators use foams to increase the sweep efficiency of CO₂-miscible floods. Given the FY91 EOR tax credit, which provides a 15% credit for eligible EOR costs, it is conceivable that, with increased costs caused by utilization of these foams, the total additional Federal revenues attributable to advanced technology could decrease. The results of this study demonstrate this potential scenario. As advanced technology projects are implemented, the amount of the available tax credit could increase, leading to smaller Federal revenues under advanced technology than under implemented technology. This decrease could range from less than \$10 million to \$18 million at oil prices of \$20/B to \$28/B. At \$36/B, after the tax credit has been completely phased out, technology advances could increase additional Federal revenues by \$37 million over the implemented technology potential for a total of over \$550 million in additional Federal revenues (Figure V-3A).

Increased production due to advanced technology EOR could replace oil imports on a barrel-for-barrel basis, improving the nation's energy security and reducing the trade deficit. The trade deficit could be reduced by the direct value of the avoided imports. Money that would have flowed to oil exporting countries instead would circulate within the U.S. economy. At \$20/B, advances in technology could add \$18 million to implemented technology imports avoided for a total of over \$750 million. At an oil price of \$24/B, \$176 million in avoided imports could result from application of technology advances, about 6% of the \$3.0 billion in potential imports avoided. The increase in avoided imports attributable to technology increases could almost double going from \$24/B to \$28/B, but it still accounts for only 9% of the \$3.9 billion in potential imports avoided (Figure V-3B).

Figure V-3

National Impact of EOR Production

Implemented Technology vs. Advanced Technology

A) Direct Federal Revenues

B) Imports Avoided*

* To the extent that 1 barrel of domestic oil replaces 1 barrel of imported oil, imports avoided measures the reduction in the foreign trade deficit

C. RECOVERY OF THE REMAINING MOBILE OIL RESOURCE

1. "Advanced" Technology Defined

The advanced secondary recovery (ASR) advanced technology analysis, designed to reflect the potential technological improvements possible from a focused RD&D program in geological reservoir characterization, is conducted in a manner consistent with the implemented technology case analysis. A major assumption is that RD&D will allow geologic reservoir characterization techniques to be widely applied, resulting in infill drilling that is targeted only into those portions of the reservoir where project economics will allow drilling at closer spacings. This will improve the project economics of ASR, resulting in more activity and much greater recovery under the advanced case than would be possible under the reservoir-wide, blanket drilling program assumed in the implemented technology case. Heterogeneous portions of reservoirs contain a proportionally larger amount of unrecovered mobile oil that is trapped in isolated compartments or bypassed by the injection fluids in conventional recovery operations. By contrast, the more homogenous portions of reservoirs exhibit more efficient conventional recovery and require less intensive drilling. In this study, infill drilling potential is evaluated by dividing each reservoir into two parts, a more continuous (homogeneous) segment and a less continuous (heterogeneous) segment. The economic recovery potential is evaluated independently in each segment, and the closest economic well spacing for each segment is independently selected.

The improved recovery methods discussed in this analysis could have a substantial impact on ASR reserve additions. Additional recovery could be stimulated as the chemical composition of polymer injectants is improved to withstand higher reservoir temperatures (up to 250° F) and/or formation salinities (up to 200,000 parts per million). These improvements would increase the marginal impact of the profile modification and polymer flooding projected under the implemented technology case whether they are applied alone or in combination with infill drilling. Additional benefits were estimated from the reduction of the associated risk (modeled as a reduction in hurdle rates with technology advances as discussed in Chapter III) of ASR processes as currently implemented.

2. Production and Reserves

The development of advanced technology ASR methods through RD&D could significantly increase the state's oil reserves. The advanced case ASR reserves could range from 680 million to nearly

870 million barrels in the reservoirs evaluated for this study, 285 million to over 330 million barrels greater than the incremental reserves generated under implemented technology across the oil prices considered (Figure V-4). Incremental reserves could be substantial at lower prices, totaling 680 million barrels and over 790 million barrels of incremental oil at \$16/B and \$20/B, respectively. ASR is less sensitive than EOR to increases in oil price at the higher end of the analyzed price range. Under implemented technology, as the price rises from \$20/B to \$24/B, incremental reserves could increase by 18%; at the same price increments in the advanced technology case, incremental reserves could increase by only 6%. Despite the relatively low growth in incremental reserves as the price of oil increases, the total additional reserves from advanced technology ASR could be substantial. The nearly 870 million barrels in incremental reserves at \$28/B with advanced technology represents a 20% increase over New Mexico's 1991 proved reserves (721 million barrels).

Figure V-4

Incremental Reserves by ASR Process Implemented Technology vs. Advanced Technology

Table V-2A shows the distribution of the incremental reserves by ASR process. Infill drilling in combination with profile modification or polymer flooding could be the most prolific advanced technology recovery method, contributing from 66% to nearly 71% of the total incremental reserves. Infill drilling alone could generate between 23% and 27% of total incremental reserves from advanced technology ASR. Profile modification and polymer flooding could contribute between 6% to 7% of the total recovery in the advanced technology case, a slightly higher portion than under implemented technology.

Geologically targeted infill drilling, by itself or in combination with profile modification or polymer flooding, could generate incremental reserves roughly one and a half to two times greater than those estimated in the implemented technology blanket infill drilling case at all oil prices considered. These dramatic increases could occur for two related reasons. First, an improved understanding of reservoir architecture and the nature of heterogeneity would allow wells to be economically justified at much closer spacing than is currently possible. As these new wells contact additional volumes of oil, ultimate recovery would be improved. Second, the ability to target infill wells would eliminate the unnecessary wells that would be drilled under a blanket infill drilling program. Targeting infill wells would reduce the front-end investment for each project undertaken, making some otherwise uneconomic projects cost-effective. As observed in the implemented technology case, the contribution of profile modification and polymer flooding to total incremental reserves could be fairly constant across the oil prices analyzed, adding 49 to 57 million barrels, or about three times the reserves from these processes under implemented technology. As previously noted, the competition of these processes with more prolific methods such as infill drilling and combination processes could limit the contribution of profile modification and polymer flooding applied alone.

Table V-2B shows the estimated number of economic ASR projects for both the implemented and advanced technology cases. At oil prices above \$20/B, although the number of infill drilling projects could be lower under advanced technology (at \$16/B, the number of projects is 40% lower), the incremental reserves associated with these projects do not decrease dramatically. The maintenance of reserves totals despite the decrease in projects emphasizes the effectiveness of targeting infill wells to the more prolific portions of the reservoir. Advances in technology could have a much larger impact on the number of combination projects and on the number of profile modification and polymer flooding projects that could become economic.

For combination projects, the economics of most projects could be favorably improved by advanced technology because a well-designed, strategic infill drilling program reduces the overall

Table V-2A

**Incremental Reserves from ASR by Process
Implemented Technology vs. Advanced Technology
(Million Barrels)**

Oil Price (\$/B)	Polymer Flooding and Profile Modification		Infill Drilling		Infill Drilling and Polymer Flooding or Profile Modification		Total	
	Implemented	Advanced*	Implemented	Advanced*	Implemented	Advanced*	Implemented	Advanced*
\$16	16	49	206	159	170	469	392	677
\$20	16	51	141	181	238	561	395	793
\$24	16	52	204	220	247	567	467	839
\$28	16	57	245	235	252	575	513	867
\$32	16	57	247	236	251	573	514	866
\$36	16	57	269	236	252	576	537	869

* This is the total reserves with advanced technology -- implemented technology plus the increment due to technology advances.

Table V-2B

**Estimated Number of Economic ASR Projects by Process
Implemented Technology vs. Advanced Technology
(Project Counts)**

Oil Price (\$/B)	Polymer Flooding and Profile Modification		Infill Drilling		Infill Drilling and Polymer Flooding or Profile Modification		Total	
	Implemented	Advanced	Implemented	Advanced	Implemented	Advanced	Implemented	Advanced
\$16	2	5	8	5	6	10	16	20
\$20	2	5	7	7	7	14	16	26
\$24	2	5	10	8	8	16	20	29
\$28	1	7	15	9	8	17	24	33
\$32	2	7	16	9	8	16	26	32
\$36	1	7	18	9	8	16	27	32

investment required in a given reservoir. The number of economic profile modification and polymer flooding projects could increase significantly from the implemented case. The number of economic projects could increase as a result of assumed improvements in the chemical composition of polymer solutions that allow these solutions to withstand more severe reservoir conditions. Such technological advances could make more reservoirs technically and economically amenable to the application of chemical treatment processes.

Figure V-5 displays the projected annual production that could result from ASR technology advances at oil prices of \$16/B and \$32/B from the analyzed New Mexico reservoirs. In both cases, a significant amount of oil could be added to the state's production over the next 25 years. Annual production from ASR has been determined in this study as a function of rig availability and technology transfer. As a result, some fields will be abandoned before ASR can be implemented. The timing assumptions also lead to sharp production increases after the year 2000 as technology is phased in and increasing numbers of reservoirs reach their economic limit under conventional recovery operations. Under advanced technology, there is a time delay as RD&D is performed; 27% of the potential resource could therefore be abandoned before advanced technology ASR projects could be implemented.

Annual production from ASR reserves could add significantly to New Mexico's production levels under advanced technology. These large increases, however, would not occur until after the year 2005. At \$16/B, advances in technology could add 1.4 million barrels per year to the production levels possible under implemented technology between the years 2000 and 2005 (Figure V-5A). Advanced technology ASR production could peak in the year 2016 at nearly 23 million barrels per year and average almost 20 million barrels per year from the year 2006 to 2020, over 75% greater than the levels under implemented technology. A 20 million barrels per year production rate could increase New Mexico's 1991 production rate by nearly 28%. At \$32/B, the gains in production again would occur after the year 2005 (Figure V-5B). From the year 2000 to 2005, technology advances could add over 1.6 million barrels per year on average to implemented technology potential. After 2005, advanced technology annual production could average nearly 25 million barrels per year through the year 2020, over 10 million barrels per year more than the potential under implemented technology.

Figure V-5

Annual Production from ASR Reserves

Implemented Technology vs. Advanced Technology

A) At \$16/B

B) At \$32/B

3. Effects on State Revenues and Economic Activity

Under advanced technology, New Mexico could receive over \$4 billion in total additional revenues from production taxes and oil industry-related corporate income and sales taxes from ASR if oil prices reach \$36/B (Figure V-6A). As in the implemented technology case, the revenue could mostly be generated from production taxes; these taxes could account for over 57% of the direct state tax revenues added at prices below \$32/B. At higher prices, the state EOR tax incentive (forgiveness of half of the severance taxes) is no longer in effect; production taxes therefore account for 64% of total additional state taxes. At an oil price of \$20/B, additional state and local revenues attributable to technology advances could nearly equal to those generated under implemented technology, doubling potential revenues from \$870 million to \$1.7 billion. At a \$28/B oil price, additional state and revenues from ASR projects could be significant. Over \$2.6 billion in revenues could be generated by advanced technology ASR activities, 42% of which would be attributable to technology advances.

In addition to the increases in state and local revenues, New Mexico would benefit from the stimulation of economic activity (Figure V-6B). At \$20/B, advances in ASR technology more than doubles the potential increase in economic activity from \$3.8 billion under implemented technology to \$8.1 billion. As price increases, the rate of the increase in activity diminishes, but the potential increase in activity could still be quite significant. At \$28/B, advanced technology could add \$4.6 billion to the implemented technology potential, resulting in over \$12 billion in additional state economic activity from advanced technology ASR. Figure V-6B displays the components of this increase. Intangible investments from ASR projects could make the most substantial contribution to the state's economic activity, accounting for around 30% to 37% of total activity. Direct state taxes and royalties could make roughly equal contributions (20% to 26%), with operating costs comprising the remainder.

Annual production from ASR reserves under advanced technology could create or maintain a significant number of jobs in the next 25 to 30 years (not illustrated). At an oil price of \$16/B, technology advances could create or maintain 10 jobs annually over the implemented technology average potential of 117 jobs per year from the year 2000 to 2005. Large increases in potential could be realized over the following 15 years; from the year 2006 to 2020, the number of additional of jobs per year created or maintained by advanced technology ASR activities could average nearly 395, 52% greater than the potential under implemented technology. At \$32/B, even larger increases could be realized. From the year 2000 to 2005, an average of almost 256 jobs could be created or maintained each year from activities

Figure V-6

State Impact of ASR Production

Implemented Technology vs. Advanced Technology

A) Direct State and Local Revenues

B) Direct State Economic Activity*

* To the extent that royalties go to the Federal government (i.e. fields on Federal lands), royalties as a portion of state economic activity may be overstated.

associated with advanced technology ASR production, nearly 8% greater than implemented technology potential. Over the years 2006 to 2020, technology advances could add an average of over 250 jobs per year to implemented technology each year for a total average of over 777 jobs created or maintained by advanced technology ASR activities.

4. Effects on the National Economy and Budget

The development of advanced technology for the recovery of the known UMO resource in New Mexico could also benefit the nation. Figure V-7A shows a dramatic increase in the incremental revenues to the Federal treasury from personal and corporate income taxes due to advanced technology ASR. Advances in ASR technology at \$20/B could add nearly \$1.1 billion to the potential Federal revenues under implemented technology for a total of \$2.5 billion. At an oil price of \$28/B, \$1.6 billion of the \$3.9 billion in additional Federal revenues could be attributed to advances in technology.

As discussed in the previous chapter, the nation would also benefit from increased ASR in New Mexico through enhanced energy independence and security as the domestic resource base expands. Each barrel of reserves added through advanced ASR techniques in New Mexico could replace a barrel of imported oil and reduce the nation's trade deficit by the direct value of the avoided imports. At \$20/B, the application of advanced technology ASR could double the potential imports avoided due to implemented technology ASR from \$7.9 billion to nearly \$16 billion (Figure V-7B). At \$28/B, technology advances could generate nearly \$10 billion in avoided imports, for a total potential of over \$29 billion.

D. CONCLUSIONS

As discussed in Chapter IV, currently available EOR and ASR technologies have the potential to significantly increase reserves and provide substantial economic benefits to operators, the state of New Mexico, and the nation. An aggressive and efficient technology transfer program in both the public and private sectors would bring these available technologies to operators and expedite their field applications. At an oil price of \$20/B, implemented technology EOR and ASR process could contribute over 430 million barrels to New Mexico's reserves base. At \$28/B, potential incremental reserves could reach 640 million barrels.

Figure V-7

National Impact of ASR Production

Implemented Technology vs. Advanced Technology

A) Direct Federal Revenues

B) Imports Avoided*

* To the extent that 1 barrel of domestic oil replaces 1 barrel of imported oil, imports avoided measures the reduction in the foreign trade deficit.

Advances in technology could significantly increase the potential reserves and associated economic benefits which are possible using implemented technology EOR and ASR. Technology advances could increase implemented technology potential by nearly 400 million barrels of incremental reserves at an oil price of \$20/B. The total incremental reserves at this price, 830 million barrels, could more than replace New Mexico 1991 proved reserves. At an oil price of \$28/B, technology advances could add 365 million barrels of incremental reserves, for a total EOR and ASR reserves potential of over 1.0 billion barrels. If this potential were to be realized, advanced technology EOR and ASR would nearly double New Mexico 1991 proved reserves.

The activities associated with advanced technology EOR and ASR would generate substantial direct state tax revenues. At \$20/B, \$860 million of the \$1.8 billion of potential direct state revenues are attributable to technology advances. At an oil price of \$28/B, over 40% (\$1.1 billion) of the \$3.0 billion in total potential state revenues are due to advances in technology.

The potential benefits estimated in this analysis will not be possible, however, without effective technology transfer and RD&D programs. Aggressive technology transfer needs to be undertaken by all oil-related entities (operators, producer associations, research universities, state geologic surveys, and state and Federal government agencies) in order to ensure that currently available technologies are disseminated in the oil patch and widely applied in the field. The significant additional benefits derived from technology advances clearly warrant a focused RD&D program to improve advanced oil recovery technologies.

A collaborative effort between the public and private sectors is essential to pool resources and expertise while leveraging risk. Operators, oil companies, research universities, and state geologic surveys need to join with state and local governments and the Federal government to identify the highest priority problems in reservoirs with the largest remaining resources and the greatest threat of abandonment. A focused RD&D effort targeting the identified problems then needs to be undertaken. An RD&D effort alone is not enough, however; the newly developed technologies need to be transferred to the field for wide-scale demonstration and application. The Department of Energy's Program Opportunity Notice (PON) process is currently applying some of these concepts. The PON process targets those classes of reservoirs with the largest potential resource and greatest threat of abandonments. Near- and mid-term RD&D efforts, jointly funded by the Federal government and private industry, are directed towards the producing problems of these reservoirs. The results, once successfully developed and demonstrated, are to be transferred to other operators facing similar producing conditions. While they are a start, efforts like

the PON process are not enough. A more aggressive and focused collaborative RD&D effort will greatly increase domestic production, enhance national energy security, reduce imports, and increase economic benefits associated with oil recovery.

Even after application of advanced technology EOR and ASR, a significant portion of the oil resource will remain unrecovered in the analyzed New Mexico reservoirs (Figure V-8). At the improbably high oil price of \$36/B, total ASR reserves potential could be 870 million barrels while EOR reserves potential could total over 190 million barrels. If this reserves potential were realized, over 1.7 billion barrels of mobile oil (65% of the mobile oil target) and 5.6 billion barrels of immobile oil (97% of the immobile oil target) would remain in analyzed reservoirs. In addition, over 2.3 billion barrels of remaining oil not included in this analysis, and any newly discovered oil, would still be unrecovered after application of advanced technology EOR and ASR. The known remaining oil-in-place of over 9.6 billion barrels is the target for further advances in EOR and ASR technologies.

Figure V-8

New Mexico Remaining Oil Resource After Advanced Technology Recovery

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AN EVALUATION OF KNOWN REMAINING
OIL RESOURCES IN THE STATE OF WYOMING

Project on Advanced Oil Recovery and the States

Volume IV

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Christine Hansen
Executive Director
November 1993

EXECUTIVE SUMMARY

The Interstate Oil and Gas Compact Commission (IOGCC) has conducted a series of studies to evaluate the known, remaining oil resource in twenty-three (23) states. The primary objective of the IOGCC's effort is to examine the potential impact of an aggressive and focused program of research, development, and demonstration (RD&D) and technology transfer on future oil recovery in the United States. As a part of this larger effort by the IOGCC, this report focuses on the potential economic benefits of improved oil recovery in the state of Wyoming. Individual reports for seven other oil producing states and a national report have been separately published by the IOGCC. Several major technical insights for state and Federal policymakers and regulators can be reached from this analysis.

- At the conclusion of conventional recovery operations, two-thirds of the known original oil-in-place will remain in Wyoming oil reservoirs.
- The remaining resource, 13.4 billion barrels, is the target for future improved oil recovery techniques. However, a significant portion of this remaining oil resource has already been abandoned. An even greater portion is in imminent danger of abandonment if cost-effective and efficient recovery techniques are not applied.
- Resource abandonment will significantly impact the economic producibility of future production and reserves under improved oil recovery techniques. Major capital investments will be needed to reacquire the leases, rebuild the infrastructure, and more importantly, drill new wells to regain access to the Wyoming target resource.
- Wyoming's future as a premier energy producing state depends strongly on the development of efficient and cost-effective oil recovery technologies, technology transfer to Wyoming producers, and the timely and successful application of such technologies, given the steady decline in Wyoming production and reserves and the accelerating level of well abandonment over the past decade.
- The effective transfer of existing technology could result in 310 to 380 million barrels of new reserves from analyzed Wyoming reservoirs at oil prices ranging from \$20/B to \$28/B, an amount equal to nearly 50% of the state's current proved reserves.
- Technology advances resulting from a focused RD&D effort could result in *additional* post-conventional reserves of 230 to 430 million barrels. The effective transfer of existing technology, coupled with the development and application of new technologies, could more than replace current proved reserves in Wyoming.
- Public sector revenues from future improved oil recovery activity would total between \$1.4 and \$2.3 billion given currently available recovery practices and oil prices of \$20/B to \$28/B. Technology advances could increase these totals by \$0.5 to \$1.4 billion over the same price range, with roughly 60% of the total flowing to the state treasury.

- Potential improved oil recovery would replace imports of foreign oil, keeping between \$6 and \$10 billion in the U.S. economy over an oil price range of \$20/B to \$28/B. This figure is only the direct cost of imports avoided due to increased domestic activity. The true value to the country is actually much higher due to multiplier effects as this money circulates in the economy.
- With the application of existing technology, a state tax incentive for EOR projects in the form of forgiveness of production taxes until project payout would increase reserves by roughly 40 million barrels. The tax incentive will increase direct state tax revenues by \$10 to \$40 million and stimulate between \$440 and \$575 million in state economic activity.
- With technology advances, the tax incentive will stimulate an additional 70 to 110 million barrels of reserves. While state tax revenues could decrease by \$30 to \$150 million in this scenario, between \$1 and \$1.5 billion dollars in additional economic activity could be stimulated statewide.

The analysis presented in this report is based on the databases and models available in the Tertiary Oil Recovery Information System (TORIS). TORIS is a tested and verified system maintained and operated by the Department of Energy's Bartlesville Project Office. The TORIS system was used to evaluate 53% of the original oil-in-place (OOIP) in Wyoming, 149 major reservoirs, in a consistent manner and on an individual reservoir basis. The results have been aggregated to arrive at the statewide total.

Overall, well abandonments and more stringent environmental regulations could limit economic access to Wyoming's known, remaining oil resource. The high risk of near-term abandonment and the significant benefits of future application of improved oil recovery technology, clearly point to a need for more aggressive transfer of currently available technologies to oil producers. Development and application of advanced oil recovery technologies could have even greater benefits to the state and the nation. A collaborative, focused RD&D effort, integrating the resources and expertise of industry, state and local governments, and the Federal government, is clearly warranted. With effective RD&D and a program of aggressive technology transfer to widely disseminate its results, Wyoming oil production could be maximized. The resulting increase in production rates, employment, operator profits, state and Federal tax revenues, and energy security will benefit both the state of Wyoming and the nation as a whole.

I. OVERVIEW

A. THE PROBLEM: DECLINING WYOMING OIL PRODUCTION

Nearly two-thirds of the oil discovered in the state of Wyoming will remain trapped in the reservoir at the conclusion of conventional oil recovery operations. The total known original oil-in-place in Wyoming has been estimated at over 20 billion barrels (Figure I-1). Of this, 6 billion barrels had already been produced at the end of 1991. Another 0.8 billion barrels of proved reserves are still producible under existing economic conditions, using currently available technologies. The remaining 13.4 billion barrels is the target for newer, more efficient recovery technologies and advances in geoscientific understanding that must be developed through an integrated public and private research effort.

Figure I-1

Wyoming Oil Resource

The urgency for technology development and its effective application by Wyoming oil producers has never been greater. The two factors that have combined to make technology development critical are:

- Declining state production and reserves. Wyoming oil production has declined by 38% from 1970 through 1991 (Figure I-2A). Since 1985, the production decline rate has been almost 4% per year. Crude oil reserves decreased by 26% over the 1970 through 1991 period, but since 1985 have declined at a rate similar to production (Figure I-2B). Reserve additions have not been sufficient to replace production volume, the average size of new field discoveries has been relatively small and reserves per well have decreased.
- Increased level of well abandonment. The state of Wyoming currently produces oil from roughly 11,000 wells. Many of these wells are "marginal" wells producing at or near their economic limit. In a period of high production costs and low oil price, many of these wells are being abandoned. A recent analysis by the Department of Energy (DOE) has concluded that from 37% to 45% of the nation's remaining oil resources had been abandoned by the end of 1991.¹ Well abandonments will have a significant impact on economic access to the remaining resource for application of future improved recovery techniques. It is estimated that once a lease is abandoned, it will require an oil price *increase* of \$10/B to \$25/B to rebuild the infrastructure and drill replacement wells.² Such an economic burden will not likely be justified by the incremental oil revenues from future improved recovery techniques.

The future of Wyoming oil production and reserves depends strongly on the development and application of cost-effective and efficient technology. In the past, technology advances have made substantial contributions to Wyoming oil production. The development of new exploration techniques and secondary recovery technology has acted to reverse past production declines and has allowed Wyoming to maintain and increase its producible oil and gas resources. The opportunity exists for a program of research, development and demonstration (RD&D), combined with an integrated program of technology transfer to all sectors of the Wyoming petroleum community, to arrest the decline in production and maximize recovery of the state's oil resource.

B. THE OPPORTUNITY: OIL RECOVERY THROUGH ADVANCED TECHNOLOGY

The remaining oil resource constitutes a large target for future recovery operations. The 13.4 billion barrels of known unrecovered oil in the state of Wyoming is of two types: mobile oil and immobile oil. Mobile oil, though displaceable by water, has been uncontacted or bypassed during

¹ "Abandonment Rate of the Known Domestic Oil Resource", U.S. DOE, Bartlesville Project Office, Bartlesville, OK (June 1990).

² Brashear, J.P. et al "Effect of Well Abandonments on EOR Potential," JPT, December 1991.

Figure I-2

Wyoming Production and Reserves

A) Annual Production

B) Reserves

conventional primary production or water flooding and thus remains unrecovered. Immobile oil is trapped in the reservoir pores by viscous and capillary forces and cannot be displaced by water.

The estimated unrecovered mobile oil (UMO) resource in Wyoming is 4.8 billion barrels. This oil is an important target for future improved recovery efforts. Several improved primary and secondary recovery processes (infill drilling, profile modification, and polymer flooding), collectively referred to as advanced secondary recovery (ASR), could be used in innovative ways to produce a substantial portion of this resource. These processes are relatively low in cost and could increase production levels quickly. While such techniques have already been used by some operators in selected reservoirs, continued research and aggressive technology transfer are critically needed to improve, streamline, and adapt these techniques to site-specific reservoir conditions and broaden their applications.

The 8.6 billion barrel remaining immobile oil resource in Wyoming is the target of a number of other recovery techniques. Miscible, chemical, and thermal recovery processes directed at producing immobile oil are referred to as enhanced oil recovery (EOR). While these processes generally require larger investments and higher operating costs than conventional recovery operations, they are capable of producing substantial volumes of incremental oil with significant economic benefits. Further advances in EOR technology are foreseeable if a focused, research-intensive approach is adopted to make process improvements ready for field application.

Technology Assessment Method

This assessment of the benefits of RD&D in oil recovery technology is based on the models and databases available through the Tertiary Oil Recovery Information System (TORIS). The TORIS methodology and analytical tools were originally developed by the National Petroleum Council (NPC)³ for its 1984 evaluation of nationwide EOR potential. DOE has since maintained and updated the system through its Bartlesville Project Office (BPO).⁴ DOE has also upgraded the capability of the system to

³ National Petroleum Council, *Enhanced Oil Recovery*, Washington, DC, 1984.

⁴ *Producing Unrecovered Mobile Oil: Evaluation of Potential Economically Recoverable Reserves in Texas, Oklahoma, and New Mexico*, DOE, May 1990.

evaluate the nation's unrecovered mobile oil through ASR techniques. In this report, the future potential of EOR and ASR techniques are examined with the following key assumptions and considerations:

- A total of 149 Wyoming reservoirs accounting for nearly 11 billion barrels of original oil-in-place (53% of the total known OOIP in the state as shown in Figure I-3), were individually analyzed for their EOR and ASR potential. No attempt is made to extrapolate the results to the remaining Wyoming resource not available in the TORIS database.
- Two levels of technology are considered: (1) implemented technology -- defined as the application of currently available post-conventional techniques; and (2) advanced technology -- defined as the improvements in process performance and applicability which are likely to occur over the next decade as the result of ongoing RD&D efforts.
- For each technology level, benefits were evaluated at several oil prices ranging from \$16/B to \$36/B (1991 dollars).
- All economic analyses reflect the current Federal tax structure (including the FY 1991 Federal EOR tax credit), and the specific oil production tax situation in Wyoming. In addition, the effect of a state tax incentive for EOR and ASR projects was evaluated.
- All recovery potential evaluated in this report are for future new projects only, and they do not include incremental reserves from existing EOR projects. However, the expansion to the existing projects, if technically and economically feasible, are evaluated as part of future new projects in this report.

C. BENEFITS DERIVED FROM IMPROVED OIL RECOVERY

Potential incremental reserve volumes and resulting direct state and local revenues that could be generated through improved oil recovery (EOR and ASR) techniques under both the implemented and advanced technology cases are shown in Figure I-4. Implemented technology, if more widely applied, could add between 240 and 420 million barrels of incremental reserves across the entire oil price range analyzed. Advanced technology applied to the same resource base could stimulate an additional 150 to 510 million barrels of incremental resources for a total of 390 to 930 million barrels beyond currently proven reserves. In effect, improvements in process performance and application could nearly double the reserves possible under implemented technology conditions. This clearly provides a major justification for a focused RD&D and technology transfer program.

The potential for expanded application of only EOR techniques using implemented technology is limited if prices remain at or below \$24/B; incremental EOR recovery at this price would total only about 8 million barrels. However, implemented technology EOR could add 52 million barrels of reserves at a higher oil price of \$28/B. At this oil price, advances in EOR technology could stimulate an additional

Figure I-3

Wyoming Oil Resource

Data Coverage of EOR and ASR Analyses

Source: BPO TORIS, 1992
EIA, 1992
API/AGA, 1980

295 million barrels of incremental reserves. This means that a total of 347 million barrels of potential EOR recovery exists under the two levels of technology for the analyzed reservoirs at a \$28/B oil price. Clearly, the combination of technology advances and higher oil prices could significantly increase the amount of oil economically recoverable by EOR processes in Wyoming.

The incremental reserves attributed to ASR techniques are also substantial but are impacted much less by oil price changes than EOR. About 310 million barrels of ASR reserves could be added in the implemented technology case at an oil price of \$20/B, growing only slightly to 331 million barrels as oil prices increase to \$28/B. Research on process improvements, specifically improved polymer flooding and profile modification combined with geologically targeted infill drilling, could increase ASR potential by 50% to 60%. With advances in technology, incremental ASR reserves could total about 140 million barrels more than implemented technology over the price range analyzed, for a total of 420 to 470 million barrels of potential ASR reserves.

Future advanced oil recovery activities will generate revenues for Wyoming and the Federal treasury through increased production taxes and oil industry-related sales taxes. The revenue estimates in this study consider only direct revenues from recovery activities in the analyzed reservoirs, and exclude any additional indirect benefits from multiplier or "ripple" effects within the state or national economy. Under implemented technology at \$20/B, newly implemented improved oil recovery projects in Wyoming could directly generate \$500 million in state revenues. At the same oil price, advanced technology could generate an additional \$400 million, for a total of \$900 million in state revenues (Figure I-4). At an oil price of \$28/B, application of currently available EOR and ASR technology could contribute \$800 million to the Wyoming public treasury while the application of advanced methods could increase these revenues by an additional \$900 million to a total of \$1.7 billion.

Increased production from EOR and ASR could offset oil imports, which in turn, would reduce the national trade deficit and increase national economic activity. The value of the oil produced, the product of reserves and their effective oil price, is a simple measure of Wyoming's contribution to reducing imports. As shown in Table I-1, this figure could total between \$6 billion and \$10 billion under the implemented technology scenario, over the \$20/B to \$28/B range. Advanced technology could further decrease imports by an *additional* \$4 billion to \$11 billion. The additional value of domestically produced EOR and ASR generates significant direct economic activities as capital spending, profits, royalties, and taxes are circulated through the U.S. economy rather than exported to buy foreign oil.

Figure I-4

Potential Impact of Advanced Technology

A) Reserve Additions

B) Direct State and Local Revenues

Table I-1

Summary of Benefits from Technology Advances in EOR and ASR in Wyoming

Oil Price and Technology Level	Potential Reserves (Million Barrels)	Incremental State and Local Revenues (\$ Billions)	Incremental Imports Avoided** (\$ Billions)	Increased Federal Revenues (\$ Billions)
<u>At \$16/B</u>				
Implemented Technology	243	0.3	3.7	0.6
<u>Advanced Technology*</u>	<u>148</u>	<u>0.2</u>	<u>2.3</u>	<u>0.3</u>
Total	391	0.5	6.0	0.9
<u>At \$20/B</u>				
Implemented Technology	310	0.5	6.0	0.9
<u>Advanced Technology*</u>	<u>231</u>	<u>0.4</u>	<u>4.4</u>	<u>0.2</u>
Total	541	0.9	10.4	1.1
<u>At \$24/B</u>				
Implemented Technology	328	0.6	7.6	1.2
<u>Advanced Technology*</u>	<u>340</u>	<u>0.6</u>	<u>7.9</u>	<u>0.2</u>
Total	668	1.2	15.5	1.4
<u>At \$28/B</u>				
Implemented Technology	383	0.8	10.4	1.5
<u>Advanced Technology*</u>	<u>430</u>	<u>0.9</u>	<u>10.9</u>	<u>0.5</u>
Total	813	1.7	21.3	2.0
<u>At \$32/B</u>				
Implemented Technology	414	1.0	12.5	2.0
<u>Advanced Technology*</u>	<u>450</u>	<u>1.0</u>	<u>13.0</u>	<u>1.2</u>
Total	864	2.0	25.5	3.2
<u>At \$36/B</u>				
Implemented Technology	419	1.1	14.2	2.5
<u>Advanced Technology*</u>	<u>509</u>	<u>1.4</u>	<u>16.7</u>	<u>1.7</u>
Total	928	2.5	30.9	4.2

*Advanced is incremental over implemented technology.

**Imports Avoided = Reserves times effective wellhead price; to the extent that 1 barrel of domestic oil replaces 1 barrel of imported oil, imports avoided estimates the reduction in foreign trade deficit.

D. POTENTIAL BENEFITS OF A TAX INCENTIVE

Currently, Wyoming EOR projects are exempt from the 2% state excise tax. This tax incentive expires in 1994, and was therefore not included in this analysis. Relief of state production taxes for improved oil recovery could enhance the profitability of marginal EOR or ASR projects to the point where additional reserves could be added. With such a tax incentive, Wyoming could receive new tax revenues and enjoy increased statewide economic activity. Ideally, these benefits would more than offset tax revenues foregone on projects which would have been undertaken even without the tax incentive. In other words, a tax incentive could generate more revenue than it costs.

Figure I-5 shows the effects of such a tax incentive in Wyoming by illustrating the reserves which could be added with and without the incentive, across the analyzed price range, using both implemented and advanced technologies. Such a tax incentive would be particularly effective for EOR projects at oil prices between \$16/B and \$28/B. Because ASR applications are not particularly sensitive to oil price, the tax incentive has an insignificant effect on stimulating additional ASR reserves. Accordingly, ASR applications should probably not be the target of a tax incentive.

Table I-2 illustrates the impact of production tax relief on the state of Wyoming and the nation as a whole. The table clearly shows that this incentive would be a "win-win" situation if applied to implemented technology EOR at prices between \$20/B and \$28/B. With the tax incentive:

- Operators could find certain new projects to be profitable for development;
- State tax revenues and Federal revenues will increase; and
- The citizens of Wyoming would benefit from increased statewide economic activity.

In the case of advanced technology application, policy trade-offs would become necessary since the state would have to forego some revenues in order to attain other benefits. At \$20/B, the state would lose \$32 million in tax revenue, but gain over \$940 million in state economic activity. At \$24/B, the state could trade \$34 million in taxes for over \$1.5 billion in additional economic activity. Even at \$28/B, Wyoming could benefit substantially by foregoing some state tax revenues (\$155 million) for additional in-state economic activity (over \$920 million).

Figure I-5

Impact of Tax Incentive on EOR and ASR Reserves

Base Case vs. Incentive Case

A) Implemented Technology

* At oil prices above \$28/B, the Federal EOR tax credit decreases by 2.5% for each \$1 over the \$28/B oil price; complete phaseout occurs at an oil price of \$34/B.

B) Advanced Technology

* At oil prices above \$28/B, the Federal EOR tax credit decreases by 2.5% for each \$1 over the \$28/B oil price; complete phaseout occurs at an oil price of \$34/B.

Table I-2

**Summary of State and Federal Economic Benefits and Trade-offs of
Analyzed Tax Incentive on EOR in Wyoming***

Oil Price (\$/B)	Tax Structure	Implemented Technology				Advanced Technology			
		Direct State and Local Revenues (\$ Millions)	Direct State Economic Activity (\$ Millions)	Direct Federal Revenues (\$ Millions)	Imports Avoided (\$ Millions)	Direct State and Local Revenues (\$ Millions)	Direct State Economic Activity (\$ Millions)	Direct Federal Revenues (\$ Millions)	Imports Avoided (\$ Millions)
\$16	Base	0	0	0	0	0	0	0	0
	Incentive	0	0	0	0	0	0	0	0
\$20	Base	0	0	0	0	181	1,555	30	2,273
	Incentive	30	443	3	776	149	2,497	44	3,701
\$24	Base	17	136	-1	204	362	3,212	84	4,864
	Incentive	57	678	45	1,201	328	4,765	141	6,869
\$28	Base	125	869	67	1,466	678	6,076	266	8,655
	Incentive	136	1,443	108	2,328	523	7,001	352	10,262
\$32	Base	206	1,419	179	2,254	845	7,311	761	10,651
	Incentive	153	1,585	241	2,665	627	7,958	947	12,162
\$36	Base	235	1,588	269	2,606	1,014	8,423	1,197	12,787
	Incentive	192	1,930	378	3,332	744	9,153	1,429	14,434

* The economic effects of a tax incentive on EOR only are shown here; because ASR is less sensitive to the price of oil than EOR is, the economic effects of a tax incentive on ASR are marginal.

E. CONCLUSIONS

The development, testing, and wide-scale application of currently available improved oil recovery technologies could stimulate incremental reserves ranging from 240 million to 330 million barrels from the state of Wyoming's largest, most mature reservoirs at oil prices across a reasonable range of \$16/B to \$24/B. With the technology advances resulting from focused RD&D, an additional 150 million barrels to 340 million barrels incremental reserves could be produced over this price range using EOR and ASR techniques. Even with the successful development and application of these technologies, however, about 3.5 billion barrels of immobile oil would still remain in the analyzed reservoirs as a long-term target for future advances in EOR, and 1.8 billion barrels of mobile oil would remain as a long-term target for future advances in ASR processes (Figure I-6). While this target is substantial, it unfortunately will not remain a target indefinitely. Well abandonments have already limited economic access to a portion of the resource. The timely development and application of new recovery technology is crucial to maintain economic access to the remaining domestic oil resource.

The results of this analysis have important policy implications. Domestic oil production generates significant direct revenues to Wyoming and to the Federal government and substantial additional indirect benefits to both the state and national economies. In addition to stimulating reserves, production, and economic activity, the application of improved oil technology would enhance the nation's energy security. However, integrated efforts and initiatives are needed to achieve these goals. These efforts should include:

- Collaborative RD&D;
- Aggressive technology transfer; and
- Appropriate tax and regulatory policies at the state and Federal levels.

A collaborative RD&D effort between the oil industry, universities, state and local governments, and the Federal government focused on improving advanced oil recovery technology and its application in key geologic settings would benefit operators, the state of Wyoming, and the entire nation. With sound planning and clear, attainable goals, state policies can be effectively integrated with Federal and private programs to dramatically increase production to the benefit of both the state and the nation's treasuries, economies, and citizens. State and Federal tax incentives can be instituted in order to help domestic EOR and ASR projects compete with foreign investment opportunities. In addition, regulatory policymakers could design regulations which reflect both the true risks to health, safety and the environment and the economic risk of resource loss through abandonment.

Figure I-6

Wyoming Remaining Oil Resource After Advanced Technology Recovery

II. BACKGROUND AND OBJECTIVES

A. TRENDS IN WYOMING OIL PRODUCTION AND RESERVES

Wyoming oil production, although currently accounting for roughly 4% of U.S. lower-48 production, has been on an intermittent decline for the past twenty years. Production peaked in 1970 at 160 million barrels, after increasing by over 20 million barrels during the course of the 1960s (Figure II-1), and consequently declined sharply over the next 12 years. By 1982, production stood at 118 million barrels, a decline of 26% from the 1970 high. Higher oil prices boosted production by 10 million barrels over a three year period from 1982 to 1985, but the subsequent oil price collapse in 1986 sent production downward once again. Statewide production plunged to under 100 million barrels in 1991, a six-year drop of 22%; this marked the first time since 1955 that Wyoming's production had dropped below 100 million barrels. In the future, the Wyoming production slide is likely to continue as the state's fields mature and access to the remaining reserves in known state reservoirs becomes more expensive.

Wyoming reserves began their decline earlier than production, as many of the production increases of the 1960s came from extensive in-field development of known reservoirs (Figure II-2). A thirty-year reserves high of more than 1.4 billion barrels came in 1960, before a long period of decline sapped reserves levels. Between 1960 and 1976, Wyoming reserves decreased by nearly 600 million barrels. During the next ten years, reserves levels fluctuated in the face of rising world oil prices. A ten-year high of 957 million barrels of reserves occurred in 1983 and was maintained through 1985, before the oil price collapse limited new development and reserve additions. By the end of 1991, Wyoming reserves were reduced to 757 million barrels.

Evidence of the maturity of the Wyoming oil resource can be found in the gains posted in the number of Wyoming's producing wells. Even as the number of producing wells in the state increased by 2,300 between 1970 and 1991, the rate of production declined by over 40% during this same period (Figure II-3). These new wells were largely infill development wells and, as a result, they added relatively little to the reserves. Reserves per producing well stood at 110,000 barrels in 1970, but declined to 65,000 barrels in 1991, further demonstrating the maturity of this state's oil resource.

As Wyoming's oil resource matures, an increasing proportion of its production will originate from stripper wells which produce fewer than 10 barrels of oil per day (Figure II-4). Compared to the year

Figure II-1

Wyoming Crude Oil Production (1950 - 1991)

Figure II-2

Wyoming Crude Oil Reserves (1950 - 1991)

Figure II-3

Figure II-4

1973 when only a little more than 1% of Wyoming production came from these economically marginal wells, almost 7% of Wyoming production was attributed to stripper wells as recently as 1986. The 1986 oil price collapse caused many stripper wells to be abandoned, thus reducing the overall stripper well percentage. By 1990, however, more than 5% of production was attributed to stripper wells. Over the past decade, 4,600 stripper wells have been abandoned in Wyoming; more will likely be abandoned in the near future if oil prices stay at current levels or if new recovery and operating procedures are not implemented.

Declines in Wyoming oil production have had an adverse effect on the Wyoming economy. In 1970, more than 12,000 people were employed in the state's oil and gas industries (Figure II-5). That number increased to almost 30,000 in the boom year of 1981, but has since fallen by half to about 15,000. Similarly, in 1981, \$5.0 billion (constant 1991 dollars) in annual value was generated by the state's oil industry, but by 1991, that number has been reduced by 65% to a little more than \$1.7 billion (Figure II-6). Should production or oil prices continue to drop, these losses could become even more pronounced, further damaging the Wyoming economy.

Revenues from production taxes on oil and gas reached a peak, in constant 1991 dollars, of nearly \$338 million in 1981, only to decline to \$130 million in fiscal year 1991 (Figure II-7). This significant loss in state revenues was caused by the dual effect of lower product prices and declining oil and gas production. The loss of oil and gas revenue has had a significant impact on total state tax revenues. In fiscal year 1981, when oil prices were at their peak, oil and gas production taxes contributed more than 55% of all state tax revenues (Figure II-8). This percentage has fallen dramatically to 17% of total tax revenues in fiscal year 1986 and has remained between 21% and 26% from 1987 to 1990.

At the conclusion of conventional primary and secondary recovery operations, significant quantities of oil will remain unrecovered in reservoirs that are currently discovered and mostly developed (Figure II-9). The total known original oil-in-place (OOIP) in Wyoming is estimated to be 20.1 billion barrels. Of this resource, nearly 6 billion barrels had been produced, and nearly 760 million barrels were recognized as proved reserves at the end of 1991. This total ultimate recovery of 6.8 billion barrels represents just over one-third of the Wyoming oil resource, leaving nearly two-thirds, over 13 billion barrels, as the target for newer, more efficient extraction techniques.

Figure II-5

Total Oil and Gas Employment in Wyoming (1970 - 1991)

Figure II-6

Annual Wellhead Value of Wyoming Oil and Gas Production (1961 - 1991)

Figure II-7

**Wyoming Oil and Gas Severance Taxes
(FY1971 - 1991)**

Figure II-8

**Wyoming Oil and Gas Severance Taxes as a
Percent of Total State Taxes (FY1971 - 1990)**

Figure II-9

Wyoming Oil Resource

After Conventional Operations, Two-Thirds of the Wyoming Oil Resource Will Remain Unrecovered

Total Original Oil-in-Place: 20.1 Billion Barrels

Source: BPO TORIS, 1992
EIA, 1992
API/AGA, 1980

The unrecovered oil resource can be broken down into two components: mobile and immobile oil. In Wyoming, 8.6 billion barrels of remaining immobile oil represent the target for a number of tertiary extraction techniques defined as enhanced oil recovery (EOR). The 4.8 billion barrels of unrecovered mobile oil (UMO) remain as the target for a number of advanced primary and secondary recovery processes, collectively defined as advanced secondary recovery (ASR). Recovery operations directed at each of these significant resources could play a role in sustaining Wyoming's production well into the next century and reducing the nation's dependence on foreign oil. A brief discussion of the analyzed EOR and ASR processes is contained in Volume X, Appendix A.

B. IMPROVED RECOVERY ACTIVITIES TARGETING THE REMAINING RESOURCE

The oil remaining after conventional primary and secondary recovery lies in two defined regions within each reservoir: the swept and the unswept zones. In the swept zone of the reservoir, conventional operations have recovered a significant portion of the original concentration of oil. The oil remaining in this swept zone is trapped in the reservoir pore spaces or on the surface of the pores by capillary and surface tension forces. Additional flooding with water can produce very little of this oil; the swept zone is at the "waterflood residual" level of oil saturation. The volume previously occupied by displaced oil now contains injected water (or, in some cases, natural gas). In their current stage of development, EOR processes are generally expected to reach only those portions of reservoirs previously swept by conventional techniques. Proven enhanced recovery processes are classified into three EOR categories: gas-miscible, chemical, and thermal.

In the unswept zone of the reservoir, conventional recovery processes have not swept the pore space, and the oil saturation can range from low to high depending upon the primary recovery mechanism (e.g., pressure depletion or water drive). The objective of many infill drilling programs, improved waterflooding (profile modification) projects, and other reservoir management techniques is to contact the oil in the unswept zones. Only after these zones have been swept by water are EOR operations generally considered feasible.

1. Enhanced Oil Recovery

The economics of gas-miscible flooding require a ready, sustainable, inexpensive source of injectant. The LaBarge-Big Piney area of Sublette county, Wyoming has the largest known CO₂ accumulation in the United States. Exxon has partially developed the field and is producing about 230 million cubic feet per day of CO₂ from its Shute Creek treatment plant.¹ The produced gas is 67% CO₂ and must be treated to remove methane, nitrogen, H₂S and helium. Carbon dioxide is sent via the LaBarge CO₂ transmission line to Chevron's Rangeley field in Colorado, and via the 130 mile Baroil transmission line to Amoco's Wertz and Lost Soldier fields in Carbon and Sweetwater counties, Wyoming.

¹ "Large Wyoming Source Gas Field to Fuel EOR Projects in Rockies," Oil and Gas Journal (September 24, 1984), p. 30.

Amoco's Wertz field project began in 1986 and encompasses about 1,400 acres, 60 injectors, and an equal number of producers. The target reservoir is the Pennsylvania Tensleep sand at about 6,000 ft.^{2,3} Amoco reported in early 1992 that about 3,000 of the project's 5,500 barrels of oil per day (BOPD) production rate was attributable to the injection project.⁴ Incremental oil recovery is reported to reach 16 million barrels, with a total CO₂ injected volume of 160 billion cubic feet, 69% of which will be recycled.⁵

In the Lost Soldier field, Amoco began injecting CO₂ in 1989 into the Tensleep sandstone and the Darwin sandstone-Madison limestone formation, a Mississippian sand/carbonate interval at about 5,000 feet.⁶ Amoco reports that roughly 9,000 of the total of 12,000 barrels of oil per day from the two projects is incremental production attributable to the injection project.

Wyoming is considering the possibility of providing an incentive to operators to build a pipeline from Exxon's Shute Creek plant to the Powder River Basin area.⁷ Such an arrangement would improve the economics of CO₂ injection by lowering the cost of CO₂. State funded efforts to assess the economics of small volume CO₂ injection ("huff and puff" projects utilizing truck-supplied CO₂) have shown that such small-scale operations are not economic.⁸

Four other gas injection projects are reported as being currently underway in Wyoming; two immiscible nitrogen injector projects at Chevron Painter and East Painter fields, and two Kerr-McGee

² "Amoco Eyes Significant Wyoming CO₂ Project," Oil and Gas Journal (January 4, 1988), p. 25.

³ "Amoco to Start Wyoming's First Big CO₂ Project," Oil and Gas Journal, (August 5, 1985), p. 31.

⁴ Moritis, Guntis, 1992 "EOR Increases 24% Worldwide; Claims 10% of U.S. Production," Oil and Gas Journal, (April 20) p. 51-79.

⁵ Kleinstelber, S.W., 1990, "The Wertz Tensleep CO₂ Flood: Design and Initial Performance," JPT, May 1990, p. 630-636.

⁶ *Ibid.*

⁷ "Exxon Could be Forced to Build CO₂ Line," Improved Recovery Week, Vol. 1, No. 30, September 14, 1992.

⁸ "Wyoming Huff 'n' Puff Tests said Uneconomic," Improved Recovery week, Vol. 1, No. 17, June 8, 1992.

miscible hydrocarbon injection projects at Buck Draw North and Sand Dune fields.⁹ Kerr-McGee's projects began in 1988 and 1991 and target the Dakota and Muddy sandstone; together, they are producing 400 barrels of incremental oil per day.¹⁰

There are two small-scale alkaline injection projects underway in Wyoming: LL&E's alkaline/surfactant flood at its western Wyoming Doe field and KSL Enterprises alkaline/polymer flood at its Moorcroft West field.¹¹ Both projects target the Minnelusa sandstone, and both are considered economically successful. Neither reservoir had been waterflooded prior to institution of the chemical flood. LL&E expects the flood to yield an additional 463,000 barrels of oil, or seven times the total primary recovery.¹²

Three steamfloods are reported in Wyoming: DOE's Teapot Dome NPR-3, Unocal's South Casper Creek, and Amoco's Winkelman Dome. The largest project, Amoco's Winkelman Dome, began in 1964, targeting 14°API oil in the Nugget sandstone at 1,200 ft. This project is considered technically successful and is still producing 2,140 barrels of oil per day from 19 wells, 7% of which is considered incremental.¹³ Unocal's project at South Casper Creek in Natrona county began in 1981 and is currently producing 1,100 barrels of oil per day from 35 producing wells, 41% of which is considered incremental.¹⁴ The largest reservoir is the Tensleep sandstone, at a depth of 2,500 ft. and with 14°API oil.

DOE's project at Teapot Dome is in the very shallow Cretaceous Shannon sandstone (less than 300 feet), and is designed to recover light 33° API oil from 135 acres of the 400 acre unit.¹⁵ DOE

⁹ Moritis, Guntis, *loc. cit.*

¹⁰ *Ibid.*

¹¹ Moritis, Guntis, *loc. cit.*

¹² "LL&E Initiates Polymer-aided Waterflood in Wyoming," Advanced Recovery Week, January 6, 1992.

¹³ Moritis, Guntis, *loc. cit.*

¹⁴ *Ibid.*

¹⁵ "Wyoming Steamflood Project Advances," Oil and Gas Journal, January 2, 1989, p. 19.

reports that 925 of the 1,325 barrels of oil per day currently being produced is considered incremental thermal recovery oil.¹⁶ Although its application to Wyoming reservoirs may be limited compared to the other EOR processes, thermal recovery remains the predominant EOR technique used in the U.S. and could ultimately have wider applications in Wyoming.

2. Advanced Secondary Recovery

Mobile oil remains in the reservoir after conventional recovery for a variety of reasons. Foremost of these is reservoir heterogeneity, the complex variation of rock properties among zones in the producing interval. Reservoirs may consist of a large number of individual compartments, reflecting internal heterogeneity. These compartments are formed by depositional processes that originally formed the reservoir, or by diagenesis or tectonic activity that later altered the rock bodies. Exceedingly complex reservoirs may have compartments formed by all of these processes. At a given well spacing, some compartments containing oil are not in pressure communication with existing producing wells. At wide well spacings, much of the rock volume in a heterogeneous reservoir will not be contacted by existing wells, leaving large volumes of oil at or near original pressure and saturation. These compartments provide a major target for infill drilling and future recovery operations conducted at closer spacing.

Mobile oil also remains in reservoir compartments that have been contacted, but inefficiently swept by secondary recovery methods that utilize existing well configurations. At wide well spacings, significant volumes of oil are areally bypassed due to small-scale variations in reservoir continuity, the higher viscosity of oil compared to injected water, and the permeability variations within the reservoir. The effectiveness of water injection is further limited by vertical layering in the reservoir. Water preferentially enters the more permeable layers of the reservoir, leaving the less permeable rock layers unswept at relatively high remaining oil saturations.

Several geologic factors influence the volume, distribution, and potential future production of unrecovered mobile oil (UMO). A major factor commonly influencing recovery potential is reservoir genesis, or the type of system that originally deposited the reservoir rock. Internal reservoir architecture is profoundly affected by the depositional system of the initial reservoir sediment, which controls the distribution of different types of rock "packages," and by the pore structure that plays host to later

¹⁶ Moritis, Guntis, *loc. cit.*

diagenetic rock and fluid alterations. Other important geologic factors include trap style and source rocks. Reservoirs that have common depositional histories may have very similar internal reservoir architecture, but will be modified by post-depositional diagenesis. That modification will vary from basin to basin depending on geohistory.

Recovery of remaining mobile and immobile oil from known fields is a highly cost effective method for increasing oil production. A large portion of these new reserves have resulted from improved primary and secondary recovery methods, including implementation of waterflooding and pressure maintenance programs, drilling of additional wells to improve reservoir contact, and selective recompletion of existing wells to improve performance. Several distinct methods for producing UMO have emerged: infill drilling to tap uncontacted reservoir compartments, recompletion of production and injection wells to contact and sweep previously bypassed portions of the reservoir, polymer flooding to overcome unfavorable waterflood injection fluid characteristics, and profile modification to reduce the permeability contrast between reservoir layers. These techniques are all tested and proven methods for producing mobile oil remaining in the reservoir. Volume X, Appendix B discusses the ASR extraction processes analyzed in this study. Currently, there are few infill drilling and profile modification projects reported.

Over 30 polymer projects are currently in operation throughout Wyoming.¹⁷ These polymer augmented waterfloods are producing about 12,000 barrels of oil per day, roughly half of which is considered to be incremental. The earliest projects began between 1969 and 1974 in Sublette county fields producing from the Almy sandstone at about 3,500 ft. Minnelusa sandstone reservoir in Campbell and Crook counties were also popular targets for projects that a variety of independent operators began during 1985 to 1990. Most of these projects involve five or less injection wells and 10-30 producers at depths from 6,000 to 9,000 feet.

Taken alone, infill drilling, polymer flooding, and profile modification are effective processes for producing mobile oil; they are often even more effective when applied in combination, which allows the processes to complement one another. For example, polymer injection and profile modification can be used to increase the waterflood sweep efficiency not only in previously contacted compartments, but also in compartments newly contacted by infill drilling. These synergies maximize the cost-effectiveness of

¹⁷ *Ibid.*

mobile oil recovery and encourage the coordinated, multiple application of techniques in selected reservoir settings.

There are several other processes and recovery techniques which were not included in this analysis which may have potential in Wyoming. Application of these techniques would further increase potential recovery and add to the estimates contained in this analysis. Immiscible gas and nitrogen gas EOR projects could enhance Illinois oil recovery. In addition, improvements in reservoir management and improvements in waterflood patterns, waterflood rates of injection, and the timing of inception of waterfloods show significant potential as recovery techniques. To the extent that these techniques and others currently being transferred (i.e., injection water compatibility) improve potential oil recovery, the results presented in this report will be understated.

C. OBJECTIVES OF THE PRESENT STUDY

The present study analyzes the incremental reserves, public sector revenues, and statewide economic activity that could result from the implementation of the improved EOR and ASR techniques described above. The potentials for EOR and ASR production are evaluated separately, and each is considered for two technology levels: *implemented technology*, which assesses recovery potential given the widespread application of currently available technology, and *advanced technology*, which assesses the impact of the effective application of potential technological advances. Comparison of the results of these two evaluations provides the basis for assessing the benefits of improved technology provided by RD&D. All of the analyses are conducted over a range of crude oil prices from \$16 to \$36 per barrel (in constant 1991 dollars). This price range encompasses the long-term prices likely to prevail over approximately the next 30 years.

One hundred and forty-nine reservoirs, accounting for 10.6 billion barrels of original oil-in-place (nearly 53% of the total known resource in Wyoming), were included in this analysis. These reservoirs contain 6.3 billion barrels of remaining oil resource (Figure II-10). The 2.3 billion barrels of UMO is the target for application of ASR processes, and the 3.9 billion barrels is the target for application of EOR processes. To achieve the required level of application, and therefore receive the maximum benefits of both levels of technology assessed in this report, it is critical that state and local governments, the Federal government, and the oil industry work collaboratively to: (1) effectively transfer to operators currently

available technology (implemented technology), and (2) develop a focused RD&D program to improve recovery methods (advanced technology) and subsequently transfer those methods to a broad public-private audience. The results and conclusion will provide valuable insights for state and Federal policymakers in their efforts to maximize domestic production and improve the nation's energy security.

Figure II-10

Wyoming Remaining Oil Resource After Conventional Recovery Operations

III. APPROACH TO THE ANALYSIS

A. INTRODUCTION

This analysis was performed using the Department of Energy's Tertiary Oil Recovery Information System (TORIS) developed for the 1984 National Petroleum Council (NPC) analysis of the nation's enhanced oil recovery (EOR) potential.¹ Although TORIS was originally designed to evaluate EOR potential only, the system's capabilities have since been expanded to incorporate evaluations of the unrecovered mobile oil (UMO) resource, the target for advanced secondary recovery (ASR). The upgraded TORIS system assessed the recovery potential of immobile oil and UMO in the United States. The following sections in this chapter will briefly discuss the:

- Development of TORIS;
- Enhancement of TORIS to evaluate the UMO resource;
- Scope of the current analysis;
- Adaptations to TORIS for this analysis;
- Estimation of benefits, costs, and economic impacts; and
- Limitations of the analytical approach.

B. GENERAL METHODOLOGY: THE NPC BASIS

In March 1982, the U.S. Secretary of Energy requested the NPC to prepare a report on the nationwide potential and the economics of incremental EOR. The NPC is the official petroleum industry advisory committee to the Secretary. Members of NPC, who are appointed by the Secretary, represent all segments of petroleum interest, such as production, refining, marketing, and environmental, and include many chief executive officers. The NPC is supported entirely by the voluntary contributions of its members.

In response to the Secretary's request, the NPC mounted a two-year effort that consumed more than 50 professional man-years and nearly \$7 million of in-kind services. EOR experts from industry (majors, independents, service companies, and consulting firms), universities, government, and private, non-profit organizations participated. The NPC EOR study committee utilized and built upon data bases

¹ National Petroleum Council, *Enhanced Oil Recovery*, Washington, DC, 1984.

of individual reservoir characteristics and computer models that were under development by the U.S. Department of Energy's (DOE), Office of Fossil Energy. After augmentation, adaptation, and validation, the data bases and models were remanded to the DOE's Bartlesville Project Office (BPO) for maintenance, updating, and subsequent application. These data bases and models are components of a larger system, the Tertiary Oil Recovery Information System (TORIS).

By the agreement of the Assistant Secretary for Fossil Energy, the present study enjoys access to TORIS and the assistance of BPO, although its participation is limited strictly to providing the data base, models, and assistance for the technical analysis. The BPO and DOE neither contribute to nor endorse the study design or the interpretations presented in this report. The approach used by the NPC and in the present study to evaluate the EOR resource consists of the major phases listed below.

1. Reservoir Data Compilation. Detailed data describing the properties of the individual, significant oil reservoirs are compiled. Numerous public and private sources of information are consulted to complete and validate the reservoir data base. The principal elements of the TORIS data base are displayed in Table III-1. Representatives of the operating companies review the data elements of each reservoir at least three times for consistency and accuracy; automated validity checks are performed on the entire data base.
2. Resource Screening Models. Each reservoir is subjected to a screening process designed to identify the technical applicability of the respective EOR processes under what the NPC defined as "implemented," or currently available, technology. The specific criteria applied to screen each EOR process are shown in Table III-2. In addition, the reservoirs are screened under what the NPC defined as "advanced" technology, available through focused research and development. Table III-3 displays the technical criteria for "advanced" EOR technology.
3. Process Performance Models. Each reservoir that satisfies the technical criteria is then analyzed by a detailed process performance model at each level of technical applicability. The models for each process have been previously reviewed in detail and calibrated to actual field results. NPC study committees review and test this calibration. The models are reservoir-specific and, therefore, estimate incremental oil production from EOR as a function of reservoir properties and process design for each reservoir independently. Incremental production is that which is recovered in excess of production by conventional primary and secondary techniques at current field conditions.
4. Economic Evaluation. Each reservoir is then evaluated for its economic feasibility by estimating the income attributable to the incremental EOR production and the investment, operating costs, and taxes required to support the implementation of the process as designed and installed in the field. Detailed costing algorithms reflect EOR design (both "implemented" and "advanced"), reservoir depth, region, and other factors. The energy component of each cost element is adjusted to reflect the oil price being analyzed. A

Table III-1

Key Elements in the Current TORIS* Reservoir Data Base

- Original Volumetrics
 - Original Oil-in-Place
 - Reservoir area
 - Net thickness
 - Porosity
 - Initial water saturation
 - Initial oil saturation
 - Initial formation volume factor
- Current Volumetrics
 - Current oil saturation (swept zone)
 - Current formation volume factor
- Fluid Data
 - Oil gravity and viscosity
 - Connate water viscosity
 - Connate water salinity
 - Initial GOR
 - Current GOR
 - Injection water salinity
 - Crude oil fractions & properties (being added)
- Geologic Variables
 - Lithology
 - Depth
 - Temperature
 - Original and current pressure
 - Permeability
 - Permeability variation index
 - Clay content
 - Gross thickness
 - Dip angle
 - Geologic age code
 - Presence of gas cap, faults, shale breaks
 - Geologic play, depositional system, trap type
 - Areal and vertical heterogeneity descriptors
 - Pay continuity (estimated)
- Development & Performance Data
 - Recovery efficiency
 - Cumulative production
 - Annual production
 - Current injection rate
 - Cumulative volume of injectant by type
 - Well spacing
 - Number of producing & injecting wells
 - Water cut

*Tertiary Oil Recovery Information System, maintained and operated by the Bartlesville Project Office of the U.S. Department of Energy

Table III-2

Screening Criteria for EOR Candidates - Implemented Technology Case

Screening Parameters*	Units	Chemical Flooding		Miscible Flooding	Thermal Recovery	
		Surfactant	Alkaline	(Carbon Dioxide)	Steam	In-Situ Combustion
Oil Gravity	°API	---	<30	≥25	10 to 34	10 to 35
In-situ Oil Viscosity (μ)	cp	<40	<90	---	≤15,000	≤5,000
Depth	Feet	---	---	---	≤3,000	≤11,500
Pay Zone Thickness (h)	Feet	---	---	---	≥20	≥20
Reservoir Temperature (TR)	°F	<200	<200	---	---	---
Porosity (ϕ)	Fraction	---	---	---	≥0.20***	≥0.20***
Permeability Average (k)	md	>40	>20	---	250	35
Transmissibility (kh/ μ)	md-ft/cp	---	---	---	≥5	≥5
Reservoir Pressure (PR)	psi	---	---	≥MMP**	≤1,500	≤2,000
Minimum Oil Content at Start of Process ($S_o X \phi$)	Fraction	---	---	---	≥0.10	≥0.08
Salinity of Formation Brine (TDS)	ppm	<100,000	<100,000	---	---	---
Rock Type	---	Sandstone	Sandstone	Sandstone or Carbonate	Sandstone or Carbonate	Sandstone or Carbonate

* Other criteria of a geological and depositional nature were also considered. Generally, reservoirs with extensive faulting, lateral discontinuities, or overlying gas caps are not prime candidates for field-wide EOR application. These factors were considered during the manual screening step when they could be identified.

** MMP denotes minimum miscibility pressure, which depends on temperature and crude oil composition.

*** Ignored if oil saturation (S_o) X porosity (ϕ) criteria are satisfied.

Source: NPC, 1984.

Table III-3

Screening Criteria for EOR Candidates - Advanced Technology Case

Screening Parameters*	Units	Chemical Flooding		Miscible Flooding	Thermal Recovery	
		Surfactant	Alkaline	(Carbon Dioxide)	Steam	In-Situ Combustion
Oil Gravity	°API	---	<30	≥25	---	---
In-situ Oil Viscosity (μ)	cp	<100	<100	---	---	≤5,000
Depth	Feet	---	---	---	≤5,000	---
Pay Zone Thickness (h)	Feet	---	---	---	≥15	≥10
Reservoir Temperature (TR)	°F	<250	<200	---	---	---
Porosity (ϕ)	Fraction	---	---	---	≥0.15***	≥0.15***
Permeability Average (k)	md	>10	>10	---	≥10	≥10
Transmissibility (kh/ μ)	md-ft/cp	---	---	---	---	---
Reservoir Pressure (PR)	psi	---	---	≥MMP**	≤2,000	≤4,000
Minimum Oil Content at Start of Process ($S_o X \phi$)	Fraction	---	---	---	≥0.08	≥0.08
Salinity of Formation Brine (TDS)	ppm	<200,000	<200,000	---	---	---
Rock Type	---	Sandstone or Carbonate	Sandstone	Sandstone or Carbonate	Sandstone or Carbonate	Sandstone or Carbonate

* Other criteria of a geological and depositional nature were also considered. Generally, reservoirs with extensive faulting, lateral discontinuities, or overlying gas caps are not prime candidates for field-wide EOR application. These factors were considered during the manual screening step when they could be identified.

** MMP denotes minimum miscibility pressure, which depends on temperature and crude oil composition.

*** Ignored if oil saturation (S_o) X porosity (ϕ) criteria are satisfied.

Source: NPC, 1984.

discounted cashflow analysis is performed for each reservoir at a number of oil prices and minimum rates of return.

5. Technology Development. For each reservoir that is determined to be economic at a given price, the performances of the applicable EOR processes are compared. Each reservoir is then assigned the process producing the greatest quantity of incremental oil. In the NPC assessment, the reservoirs are then scheduled for development on the basis of their relative economic attractiveness and time-phased against a series of supply and environmental constraints. This procedure is modified somewhat in the present study, as described below.

The NPC reported its findings on a national basis for four oil prices, ranging from \$20 to \$50 per barrel, three minimum rates of return (zero, ten, and twenty percent), and two levels of technology performance -- "implemented," meaning available at present, and "advanced," meaning available in the future due to successful completion of currently ongoing RD&D. The present study uses the NPC reservoir data base, models, and methodology just as the NPC developed them, except as described in sections C and E. The NPC methodology is described at length in its final report.²

C. BUILDING ON TORIS: THE EVALUATION OF UNRECOVERED MOBILE OIL RESOURCES

TORIS evaluations have historically focused on the recovery of immobile or waterflood residual oil. In 1988, TORIS' capabilities were expanded to include an evaluation of the UMO resources in Texas, Oklahoma, and New Mexico.³ This expansion was accomplished by enlarging the system to consider the recovery potential of extended primary and secondary recovery operations in unswept portions of the reservoir, in a manner consistent with the current capabilities to analyze the tertiary recovery target (residual oil in previously swept zones). The system development and initial limited applications that were completed under the DOE UMO study are reported in detail in a topical report by the DOE.³

² *Ibid.*

³ ICF Resources Incorporated and the Bureau of Economic Geology, University of Texas at Austin, *Producing Unrecovered Mobile Oil: Evaluation of Potential Economically Recoverable Reserves in Texas, Oklahoma, and New Mexico*, prepared for: U.S. Dept. of Energy/Office of Planning and Environment/Office of Fossil Energy and Bartlesville Project Office, 1989.

Since 1989, the TORIS ASR models have been upgraded to more accurately describe and evaluate the UMO resources. The enhancements included the following:

- Development of an infill drilling model which processes five-spot waterflood to five-spot infill as well as five-spot waterflood to nine-spot infill;
- Development of a methodology to determine key reservoir heterogeneity elements needed for modeling infill drilling potential. The heterogeneity elements are "reservoir continuity" and "Vertical Permeability Stratification Index" (Dykstra-Parson coefficient). The methodology relies on the history match of production data to determine the heterogeneity elements;
- Validation of the infill drilling model and history match methodology on nine actual field results as well as results of a black oil simulator;
- Integration of a newly developed infill model with other models in TORIS to process infill drilling in combination with polymer flooding or profile modification; and
- Validation of criteria for implemented as well as advanced technology infill drilling.

A preliminary draft report of all developmental work is available through the U.S. Department of Energy, Bartlesville Project Office. The draft report is currently being finalized, and it will be available to the general public in the near future.

UMO, the target for advanced primary and secondary recovery operations, consists of oil that is uncontacted or bypassed during conventional production that can be displaced from the reservoir by waterflooding. "Uncontacted oil" refers to oil trapped in isolated compartments in reservoirs uncontacted by wells at current spacing, while "bypassed" oil has been contacted by existing wells but unswept by secondary recovery processes. The volume, location, and properties of the UMO depend on the geologic history of the reservoir, the fluid characteristics of the oil, and the drilling and development history of the reservoir.

Potential incremental oil recovery and related economic benefits are estimated for the three processes currently used to improve mobile oil displacement. These processes are referred to as advanced secondary recovery (ASR) and include: infill drilling, profile modification treatments (permeability contrast reduction), and polymer-augmented waterflooding. A modified polymer-waterflood predictive model is used to evaluate each process. Selected combinations of these processes are also evaluated in this study.

Consistent with TORIS EOR evaluations, the analysis of UMO considers both current technology and advanced technology. The advanced technology analysis estimates the potential improvement in recovery possible after successful RD&D. For polymer flooding and profile modification treatments, advances in technology are projected to increase both the reservoir temperature and the formation salinity thresholds that currently limit the application of these processes. Table III-4 shows the process technical screens that are used in evaluating reservoirs for polymer flooding and profile modification treatments under current and advanced technology scenarios.

Table III-4
Screening Criteria for
Advanced Secondary Recovery Processes

	<u>Polymer Flooding*</u>		<u>Profile Modification</u>	
	<u>Current</u>	<u>Advanced</u>	<u>Current</u>	<u>Advanced</u>
Reservoir Temperature (°F)	<200	<250	<180	<250
Formation Brine Salinity (ppm)	<100,000	<200,000	<100,000	<200,000
Permeability (md)	>20	>10	>20	>10
Oil Viscosity (cp)	<100	<150	<100	<150
* Source: NPC, 1984				

Infill drilling potential is also evaluated under implemented and advanced technology scenarios. Current knowledge of reservoir heterogeneity limits drilling to highly favorable reservoirs where blanket-pattern drilling at uniform spacing can yield a profit. Increased continuity in the implemented technology case is estimated by the reservoir-wide average improvement in continuity possible with a reduction in spacing to one-half the current level. The advanced technology scenario assumes that improved geologic description would target infill wells to more promising segments of each reservoir. The TORIS models represent this assumption by dividing the reservoir into two parts, a more continuous (homogeneous) region and a less continuous (heterogeneous) region. Each region is then separately analyzed to determine

its economic potential for infill drilling at subsequent one-half reductions in well spacing down to five acre spacing, or one-eighth of current spacing, the maximum reduction evaluated in this study. The specific criteria for both the implemented technology and the advanced technology infill drilling is shown in Table III-5. The entire methodology (data, models, highgrading, and analytical systems) was developed and implemented in a manner fully compatible with the existing TORIS structure.

Table III-5

Screening and Approach for Advanced Technology Infill Drilling

Technology Level	Criteria
Implemented	<ul style="list-style-type: none"> - 5-spot waterflood to 5-spot infill - 15% minimum real rate of return - Minimum well spacing of 10 acres before infill drilling - One drill down
Advanced	<ul style="list-style-type: none"> - 5-spot waterflood to 5-spot infill - 10% minimum real rate of return - Highgrade into homogenous and heterogeneous portions - One drill down in homogeneous portion - Up to three drill downs in heterogeneous portion - Well spacing after infill greater than 5 acres

D. SCOPE OF THE ANALYSIS

The cases selected for this analysis include six oil price assumptions and two levels of technology application. The cases are run, first incorporating either EOR or ASR processes individually, and then in combination. TORIS selects from five EOR recovery methods and five ASR methods for each reservoir in the database. A reservoir could be assigned only one EOR process and/or one ASR method for each case considered.

The nominal crude oil prices (West Texas intermediate adjusted for transportation costs and gravities less than 40° API) range from \$16/B to \$36/B in \$4 increments, all stated in constant 1991 dollars. The prices are selected to bracket the likely prices over the next 30 years. A minimum real (after inflation) rate of return of 10% is used to estimate discounted cash flows and project profitability for all analyses. In addition, a risk premium is also considered depending on the EOR or ASR process and the

level of technology. The risk premium is modeled as an increase in the hurdle rate as shown by Table III-6. The risk premium was recommended by the TORIS peer review committee.

Table III-6

Risk Premium For Implemented and Advanced EOR and ASR Processes

	Cost of Capital	Risk Factors		Hurdle Rates	
		Implemented Technology (%)	Advanced Technology (%)	Implemented Technology (%)	Advanced Technology (%)
Alkaline	10	15	0	27	10
Surfactant	10	15	0	27	10
In-Situ	10	15	5	27	16
Polymer	10	5	0	16	10
Profile Modification	10	5	0	16	10
CO ₂ -Miscible	10	5	0	16	10
Steam	10	5	0	16	10
Infill Drilling	10	5	0	16	10

At each oil price, two technology cases are analyzed; the "implemented" and the "advanced" case. Implemented technology reflects the applicability and level of performance of the respective processes (EOR or ASR) which are currently available. Advanced technology considers the likely improvements in process performance and applicability that can be achieved within the next decade if a focused, effective RD&D program is successfully completed.

All cases are analyzed in detail to examine their impact on estimated oil reserves, oil production, state and Federal revenues, and the state and national economies. The results of these analyses, addressing the benefits from incremental production, are reported in Chapters IV and V which discuss the effects of EOR and ASR processes for implemented technology and advanced technology, respectively.

E. ADAPTATIONS FOR THE PRESENT STUDY

Several adaptations to the NPC approach were necessary to conduct the present analysis. None is a significant departure from the NPC methodology.

1. Data Editing and Additions

Based on a lengthy data search using state and library sources, the NPC reservoir data have been reviewed and updated for 149 of the largest Wyoming reservoirs, accounting for nearly 53% of estimated original oil-in-place (OOIP) in Wyoming. The reservoirs represented in the data base include oil zones in every region of the state. The largest reservoirs are more completely represented in the data, but reservoirs as small as 5 million barrels are also analyzed in the study. The data base is, therefore, believed to be representative of the diverse oil producing formations across Wyoming. Data from the Energy Information Administration on the production of oil, gas, and water from 1970 to 1992 has been added for all reservoirs, thereby permitting decline curve analyses (used in the timing algorithm, discussed below) and validation of the estimated ultimate conventional recovery.

2. State and Federal Taxes

The present study uses current tax structure along with the actual tax rates in the TORIS economic models. The Federal taxes are estimated based on the new corporate tax rules established by Congress in the Tax Reform Act of 1986 and signed into law in October 1986. This law provides for a 34% marginal rate on corporate income taxes and changes the depreciation schedules and expense rules. In addition, the present study includes the new Federal EOR tax credit as passed by Congress in FY91. The new Federal EOR tax credit provides a credit equal to 15% of all qualified enhanced oil recovery costs on projects that began or were significantly expanded after December 31, 1990. The "qualified enhanced oil recovery costs" are defined as tangible property investments, intangible drilling and development costs, and purchase costs of tertiary injectants. The tax credit is contingent upon professional certification, in advance, that the EOR project is capable of producing more than an insignificant increase in ultimate recovery. Because the goal of the incentive is to make the application of EOR techniques economic at lower oil prices, where project economics are most impacted, the incentive is gradually phased out at oil prices above \$28/B. For every \$1/B that the average benchmark price for the preceding year exceeds \$28/B, the incentive is reduced by 2.5 percentage points for the subsequent year, so that a complete

phasing out of the incentive would occur at an oil price of \$34/B. The study also accounts for the current state tax structure in Wyoming. A state tax incentive which provides forgiveness of all production taxes on the incremental production associated with EOR and ASR projects until the point of project payback was also assessed.

3. Cost and Price Data

An informal survey of industry representatives has determined that the NPC costing algorithms for investments are still valid for the present study, provided that prices analyzed are consistent with the year of the cost data. The only exception to the use of the NPC's cost algorithms is the cost of enhanced recovery injectants delivered to the field. The NPC assumed a CO₂ purchase price in the Permian Basin of West Texas and Eastern New Mexico of \$1.25 per thousand standard cubic feet (Mcf) at an oil price of \$30/B. The NPC adjusted for changes in oil price using the equation:

$$\text{CO}_2 \text{ Price (\$/Mcf)} = \$0.50 + \$0.025 \times \text{Oil Price (\$/B)}.^4$$

However, the base price and adjustment equation were established at higher oil prices and before the completion of major CO₂ pipelines or significant CO₂ deliveries to the region. An informal poll of pipeline and field operators suggests that the CO₂ prices at present and into the near future will be lower (relative to oil prices) than the NPC had assumed. The CO₂ purchase price in West Texas has been adjusted for changes in oil price using the equation:

$$\text{CO}_2 \text{ Price (\$/Mcf)} = \$0.50 + \$0.02 \times \text{Oil Price (\$/B)}.$$

This equation results in a CO₂ price of \$0.90/Mcf at the \$20/B oil price. CO₂ prices in other regions of the state are assumed to be double the West Texas price, based on previous NPC surveys.

Chemical injectant costs have also been adjusted based on a survey of operators and suppliers. Polymer costs, assumed to be \$1.60 per active pound by the NPC, have been reduced to \$1.33 per active pound based on the current cost of low temperature, low salinity polymers. The cost is increased where oil and reservoir properties dictate the use of high molecular weight polymers. Surfactant costs used by

⁴ National Petroleum Council, *Enhanced Oil Recovery*, Washington, DC, 1984.

the NPC were based on a primary surfactant cost of \$0.32 per active pound and a secondary surfactant cost of \$0.44 per active pound. The surfactant slug cost based on these components was \$7.00/B. Prices paid by operators in recent field tests show this cost to be too low. Survey information shows that primary surfactant costs are higher (\$0.63/active pound), resulting in a \$10.17/B surfactant slug cost at a \$30/B oil price.⁵ Chemical costs have been adjusted for oil price changes as had been done in the NPC analysis, based on the energy component of the chemicals for different oil prices.

4. Benefits Estimation

The NPC did not calculate all of the individual items used in the present study's estimation of benefits. Special algorithms have been developed to estimate the number of jobs created, wages paid, and personal income taxes collected based on other elements already contained in the economic model. These algorithms are discussed further in Section F of this chapter.

5. Project Timing

The NPC's national perspective permitted a timing algorithm based principally on the assumption that the most economically attractive reservoirs would be developed first, given some broad constraints. A more detailed timing approach for both EOR and ASR was used in the present study. Timing for the application of EOR recovery techniques is estimated in two steps. First, project starting dates for EOR that are documented in the literature are used to time recently started operations. Second, when project start up dates are not available, the year that average well abandonment will occur for each reservoir under conventional recovery is estimated. This abandonment date is based on the projected rate of decline and economic limit of conventional recovery for each reservoir. EOR recovery is then phased in to occur reservoir-wide, at the latest, by three years following the estimated abandonment date. Projects that are not timed in by this data are assumed abandoned and are excluded from the analysis. The timing of ASR reserves development and production was accomplished using the Crude Oil Policy Model (COPM) because the TORIS timing model was not suited for ASR for technical reasons. COPM simulates the development of an aggregate resource as a function of project economics, while simultaneously accounting for abandonment of the undeveloped portion of the resource and technology transfer constraints. Inputs

⁵ Ray, et al., *Potential Crude Oil Production from Enhanced Oil Recovery*, U.S. Department of Energy, Bartlesville Project Office, 1986.

to COPM include the total resource potential, development and production costs, technology availability dates, technology penetration rates, abandonments rates, and reserves development rates. Outputs from the model include annual production, reserve additions, abandonments, development costs, operating costs, wages, and taxes. Reserves estimates were supplied by TORIS.

Total reserves were disaggregated into two categories, reserves available with implemented technology and incremental reserves available through the application of advanced technology. Appropriate model parameters were selected for each of these resource categories. The technology availability dates were set to 1993 for implemented technology and 2000 for advanced technology. Technology penetration rates were set at 75% in 12 years for implemented technology and 75% in 8 years for advanced technology, with the advanced technology case representing an aggressive technology transfer effort. Abandonment rates for both implemented and advanced technology were set to 3% of the undeveloped resource per year prior to technology availability and 1.5% per year after technology becomes available. Reserves development rates corresponded to typical field development profiles.

F. ESTIMATION OF BENEFITS, COSTS, AND ECONOMIC IMPACTS

The NPC study analyzed each reservoir from the perspective of the operator deciding whether to implement advanced oil recovery processes. The present study does the same in evaluating the economic viability of each reservoir. Thus, the benefits and costs to the operators are explicitly captured in the net cash flow calculations of individual projects. Under each of the various cases analyzed, projects yielding a net present value greater than the hurdle rate are assumed to be developed. This assumption is the basis for the projection of potential incremental production and reserves.

The incremental benefits and costs of EOR and ASR are estimated and reported on an annual as well as a cumulative basis. As previously discussed, reservoir timing is based on the estimated abandonment of the resource due to production decline, except for major reservoirs in which activity suggests earlier project start dates. Projects are phased in over a 5- to 10-year period to achieve full project development before this abandonment would occur. Annual estimates of benefits are based on the total economic resource produced in a given year. These annual values are reported for a twenty-seven year period, 1993 to 2020. Cumulative benefits include the sum of the annual benefits plus any additional benefits that would accrue after 2020. The total length of time for the life of all projects varies considerably depending on the process, oil price, and tax treatment. The vast majority of cumulative

production and benefits occur in the twenty-seven year period of focus in this study. The additional benefits that occur after 2020 are generally small relative to the total benefit, but important to the overall aggregate analysis.

1. Benefits to State and Local Treasuries

The benefits to Wyoming state and local treasuries from advanced oil recovery processes are the additional tax revenues attributable to implementation of the projects. These taxes include sales tax on equipment and material purchases and production taxes on the incremental production. Evaluating these benefits under the current tax structure involves estimating the sum of these revenues as they apply to the development of the projects and the activities associated with the incremental production from improved recovery projects.

2. Direct State Economic Effects

The effect on the state's treasury is only one segment of the benefits of advanced oil recovery processes. The citizens of Wyoming also gain from the increased economic activity. Only the direct effects of the incremental activity are included, not the economic "multiplier" or indirect "ripple effect" activities (e.g., pipeline construction, retail sales, etc.). The direct impact on the state's economy is defined as the sum of net revenues to the state and local treasuries (as presented above); royalties to individuals, corporations, and the state; expendable (intangible) drilling materials and services; and operating costs excluding injectant purchases. It is assumed that these funds flow predominantly to the state of Wyoming and its citizens.

Excluded from this state economic activity definition are cashflows that generally benefit citizens of other states in larger proportion than they benefit the citizens of Wyoming. These include costs for tubular steel products installed in wells, injection and production equipment, purchased tertiary injectants, and other oil field materials typically manufactured out-of-state. To the extent that these goods are marketed by distributors in Wyoming, the direct benefits of these "retail pass-through" to the state are omitted from the estimates of direct state economic activity. Similarly, while it is recognized that a portion of tertiary injectants, especially chemicals, may originate in Wyoming (generating royalties, employment, taxes, and/or other economic activity), estimating these quantities is outside the scope of the present study. Other excluded items include Federal taxes, corporate debt service, and return on capital.

While the citizens of Wyoming obviously benefit from these excluded elements as U.S. citizens, or as employees and stockholders of companies providing services, they share them with a much larger population. Thus, the definition used for direct economic effects understates the actual benefits to the state of Wyoming and its citizens.

The additional jobs, wages, and benefits created by improved oil recovery are also estimated. Labor costs (wages and fringe benefits) are calculated by isolating the labor component of all major cost elements. Table III-7 summarizes the major cost elements and their respective labor and material components. Labor costs are converted into estimated numbers of jobs by dividing total wages by the average oil field wages (including benefits) reported by the U.S. Department of Labor.⁶ Sales tax revenues are calculated based on the materials component of these costs, assuming purchasers would pay the appropriate state tax on these goods.

3. National Effects

The Federal government benefits substantially, both directly and indirectly, from increased recovery of the Wyoming oil resource. Direct Federal taxes total 5% to 20% of the value of each barrel of oil recovered. Each additional barrel of Wyoming oil production can replace a barrel of imported oil. Therefore, each dollar used to purchase the incremental barrels of oil that would otherwise pay for imports is, potentially, a dollar reduction in the trade deficit.⁷ To estimate the direct effects on import replacement (i.e., excluding multiplier effects), the gross revenue from the additional production is used. This measure of gross revenues incorporates direct in-state economic activity and excludes elements discussed in the section above. In this sense, the estimated increase in import replacement represents a more complete measurement of direct economic impacts, excluding multiplier effects. In addition, corporate and individual Federal income taxes are estimated to assess the direct effects of incremental oil recovery in Wyoming on the Federal treasury.

⁶ U.S. Department of Labor, Bureau of Labor Statistics, 1985.

⁷ Although constraints caused by limited financial or personnel resources may result in delayed national benefits due to short-term deferral of projects in other states, the aggregate benefits to the nation should be achieved as all economic projects will ultimately be developed.

Table III-7

Labor and Materials as Percentage of Total Cost in EOR Projects

<u>Investments</u>	<u>% Labor</u>	<u>% Materials</u>	<u>% Other</u>
Drilling Wells	18	55	27
Work-overs	15	63	22
Equipping Wells	10	50	40
Pipe Installation	10	50	40
Plant Installation	16	46	38
<u>Expenses</u>			
Field Operations	33	58	9
Plant Operations	38	57	5
Production Treating	0	100	0
Overhead	100	0	0

Sources:

Investments

- Drilling and Work-overs
 - NPC, 1984
 - EIA, 1984
 - Professor Neil J. Dikeman, University of Oklahoma, 1986
- Equipping Wells
 - Industry estimate
- Pipe Installation
 - Industry estimate
- Plant Installation
 - Modern Cost Engineering Technologies, Herbert Popper, page 82-83

Expenses

- Field Operations
 - EIA, 1984
- Plant Operations
 - NPC, 1984
 - EIA, 1984 (power and chemicals)
- Production Treating
 - By definition
- Overhead
 - NPC, 1984

G. LIMITATIONS TO THE ANALYTICAL APPROACH

The approach followed by this study has limitations that should be considered in utilizing its results. Some of these follow from the adoption of the NPC methodology; others result from the need to limit the scope of the present effort. It is also important to note that the results of this analysis are not forecasts of future oil recovery; they are estimates of the recovery potential of selected EOR and ASR processes.

The NPC approach, while the most credible and flexible methodology available, has certain distinct limitations. One problem is the reliance on averaged reservoir and fluid properties. Oil reservoirs are actually highly heterogeneous, with erratic properties throughout the field. The use of averaged properties belies the fact that portions of an individual reservoir could be highly attractive as an advanced technology oil recovery prospect even if the whole reservoir, on average, is not economic. Given the present methodology, reservoirs must be economically accepted or rejected as whole units, unless advanced geoscientific knowledge allows the reservoir to be evaluated in segments. The methodologies of both the present study and the NPC assume that the least favorable 20 percent of any reservoir would not be developed under EOR or ASR operations.

A second limitation is the use of regional costing algorithms. Although developed from the best available data and explicitly adjusted for variations in energy costs and specific reservoir characteristics, they do not reflect site-specific cost variations applicable to specific operators. Thus, this study does not necessarily use the actual costs of individual projects. To the extent that the average costs used understate or overstate the true project costs, the actual results will be higher or lower than the analysis estimates.

A third limitation is the use of simplified process performance models. While the models used in this project are extensively calibrated, they are designed to analyze large numbers of individual reservoirs quickly and simultaneously. Therefore, while they incorporate all the relevant reservoir engineering concepts, they are relatively simplified and generalized. In this simplified state, the models cannot be as accurate as highly detailed reservoir simulators in which very specific reservoir features and process designs may be evaluated (such as assessments used in the actual design of specific projects). The present study assumes these models are appropriate for aggregate analyses but not necessarily for individual reservoirs. Further, these models are explicitly designed to estimate only incremental recovery resulting from advanced oil recovery processes after completion of conventional production operations.

Laboratory and limited field data suggest that application of some of these techniques before the economic limit of conventional recovery could yield more than the sum of conventional and advanced oil recovery, but this is not reflected in the models.

An additional limitation arises from the methodological convention of "constant price" analysis. The use of this convention is consistent with the NPC's original nationwide study, conducted during a period of relatively stable, rising oil prices, and differentiates the effect of oil price from other effects. It can, however, cause a distortion, especially in times of declining or radically changing oil prices. The "hidden" assumption of this convention is that each of the respective oil prices analyzed must be attained by the time (and be expected to continue at that level after) the decision to commit specific reservoirs to enhanced recovery or advanced mobile oil recovery operations is made. This decision is generally made several years before the reservoir's final, actual economic limit is reached under conventional technology. To the extent this condition is not met, existing wells reaching their economic limits at lower prices will be shut-in and abandoned, making them unavailable for use in advanced oil recovery projects, as assumed. The economic model assumes that all existing wells will be utilized in future operations, although older wells may require workovers. Should "premature" abandonments occur, these wells would need to be redrilled, resulting in additional incremental investment not included in this analysis (although necessary workovers are included in the assumed cost). Redrilling would result in substantially increased costs and would thus increase the minimum oil price at which advanced oil recovery processes are profitable for certain reservoirs. The net effect of this analytic convention could overstate the economic reserves and production and the corresponding economic benefits. Under these conditions, the "constant price" convention introduces an optimistic bias to the present analysis.

Finally, the analysis follows the NPC approach, which assumed that project operation would be conducted by an integrated major oil company. This approach, in most cases, presents the least favorable corporate tax treatment for investments and revenues from advanced oil recovery projects and assumes a relatively high overhead on operations. Independent producers operate with a different corporate structure, tax situation, and overhead rate. Because most costs used in this analysis are not affected by total project size and some non-integrated operators would enjoy more favorable tax treatment, smaller independent producers should receive the same benefit as a major oil company from application of advanced oil recovery processes, possibly even at lower oil prices than projected in this evaluation.

None of the above limitations invalidate the results of this analysis. Given the uncertainty of the size and combinations of the optimistic and pessimistic biases introduced by these limitations, it is assumed that the approach is valid and the resulting projections are reasonable. To avoid misinterpretation of particular reservoirs, and to respect the confidence in which some project and ~~reservoir~~ data were obtained, no reservoir specific data is provided in the reports generated from this analysis. However, in cases where the results seemed unusual, the modeling specifications for specific reservoirs were examined in-depth to ensure the validity of the results.

IV. INCREASED RECOVERY FROM THE KNOWN REMAINING OIL RESOURCE IN WYOMING UNDER IMPLEMENTED TECHNOLOGY

A. INTRODUCTION

This chapter discusses the post-conventional reserve additions and potential economic impacts attributable to the application of currently available (implemented technology) oil recovery methods in analyzed Wyoming reservoirs. Chapter V discusses the incremental reserves and benefits under advanced technology methods attainable through RD&D. The TORIS reservoirs analyzed in this study are individually modeled to evaluate their potential for incremental production and reserves by tertiary and advanced secondary recovery techniques under a variety of oil prices and economic conditions. Some key technical assumptions and considerations regarding the analysis in this report are:

- The incremental production and reserves refers to future recovery estimated for the analyzed EOR and ASR techniques. Such production and reserves are above and beyond the recovery attainable by primary and secondary recovery techniques.
- Both light oil (API > 20 degrees) and heavy oil (API ≤ 20 degrees) resources are considered in this analysis.
- All EOR and ASR recovery potential evaluated in this report reflect future new projects only, and they do not include incremental reserves from existing (ongoing) EOR and ASR projects. However, the expansion to the ongoing projects, if technically and economically feasible, are evaluated as part of future new projects in this report.

All reservoirs are screened for technical criteria and are analyzed in detail using the process performance and economic models described in Chapter III. The results are based on the evaluation of 149 reservoirs in Wyoming for their EOR and ASR potential. The results of this analysis were not extrapolated to the rest of the reservoirs making up the Wyoming resource.

B. RECOVERY OF THE REMAINING IMMOBILE OIL RESOURCE

1. Production and Reserves

Over the price range analyzed, EOR processes (gas-miscible, chemical, and thermal) could stimulate from 8 million to 85 million barrels of incremental reserves under implemented technology

(Figure IV-1A and Table IV-1A). The upside potential would represent an 11% increase in the state's 1991 proved reserves (757 million barrels). No projects were economic at oil prices below \$24/B. However, as the oil price rises to \$24/B and higher, incremental EOR reserves could become economically attainable. The 8 million barrels of incremental reserves from EOR at \$24/B could increase by an estimated 44 million barrels, with a \$4/B increase in the oil price. At \$32/B, currently available EOR technologies could stimulate an additional 31 million barrels of incremental reserves for a total potential of over 83 million barrels. At historically high oil prices (\$36/B), EOR techniques could generate 85 million barrels of incremental reserves.

Among the EOR processes considered in this analysis, chemical (surfactant and alkaline) floods could generate the largest incremental reserves at all analyzed oil prices. At an oil price of \$24/B, chemical flooding could account for all of the incremental reserves from EOR. At \$28/B and \$32/B, chemical flooding could contribute 75% and 47% of the potential incremental reserves, respectively. At \$36/B, chemical flooding could still contribute 46% of the total potential incremental reserves from the analyzed Wyoming reservoirs.

The recovery potential of other EOR processes is more limited in Wyoming. CO₂-miscible flooding exhibits some potential at prices of \$28/B and above. CO₂-miscible flooding could generate from 13 million to over 20 million barrels of incremental reserves at oil prices ranging from \$28/B to \$36/B, accounting for 20% to 25% of the total incremental reserves. The application of thermal flooding would also be limited, but these processes could still contribute up to 31% of the total incremental reserves at oil prices of \$32/B and above.

Table IV-1B shows the number of EOR projects that could be initiated at different oil prices. Of the 149 reservoirs evaluated in this analysis, all of which are technically amenable to one or more EOR process, only 5% would be economic to develop with current EOR technology at an oil price of \$36/B. At an oil price of \$24/B, only one chemical flood could be economically feasible. Even at an oil price above \$24/B, only four CO₂-miscible and two thermal EOR projects could become economic. In most cases, the economic projects are in the large reservoirs, but size alone is not a major determinant of EOR economics.

The timing of project initiation in each reservoir that is economic at a specific price is scheduled according to that reservoir's projected conventional production decline rate. The annual incremental

Table IV-1A

**Incremental Reserves from EOR by Process
Implemented Technology
(Million Barrels)**

Oil Price (\$/B)	CO ₂ -Miscible	Chemical	Thermal	Total
\$16	0	0	0	0
\$20	0	0	0	0
\$24	0	8	0	8
\$28	13	39	0	52
\$32	18	39	26	83
\$36	20	39	26	85

Table IV-1B

**Estimated Number of Economic EOR Projects by Process
Implemented Technology
(Project Counts)**

Oil Price (\$/B)	CO ₂ -Miscible	Chemical	Thermal	Total
\$16	0	0	0	0
\$20	0	0	0	0
\$24	0	1	0	1
\$28	2	2	0	4
\$32	3	2	1	6
\$36	4	2	1	7

production resulting from EOR is determined by phasing in economic projects based on the demonstrated economic limit of conventional production as discussed in Chapter III. Figure IV-1B shows the expected annual production from all EOR processes for oil prices of \$24/B and \$32/B. Depending upon the oil price, projected annual production could initially peak between the years 2006 and 2009. At \$24/B, EOR production could reach 300 thousand barrels annually by the year 2006, and remain constant until 2014. The \$32/B annual production curve peaks at 3.3 million barrels in the year 2009, and remains constant until the year 2012.

2. Increases in State and Local Revenues

EOR production could also increase state and local revenues through production taxes and sales taxes on purchased materials used in the projects. The revenues projected in this study are generated directly from oil production or operations in the analyzed reservoirs. The revenues from other activities indirectly stimulated by the increase in economic activity are not considered. State and local revenues generated over the life of the EOR projects vary considerably with oil prices (Figure IV-2). A significant portion of these revenues could result from production taxes. At \$24/B, nearly \$17 million in incremental revenues could be generated, with production taxes contributing over 88% of the total and sales tax revenues accounting for the remainder. A \$28/B oil price could yield production tax revenues of \$110 million plus \$15 million in sales tax receipts. At \$32/B, EOR could stimulate \$206 million in additional state and local revenues. At the highest price case of \$36/B, \$235 million of additional state and local revenues could be generated.

3. Effects on the State Economy

In addition to the incremental state and local revenues, enhanced oil recovery would benefit Wyoming by increasing economic activity and by creating or maintaining jobs. The effects of EOR on the state economy are estimated conservatively: (1) only direct effects are included (i.e., no economic multiplier due to secondary effects); and (2) the direct effects are limited to benefits believed to accrue predominantly to the state of Wyoming and its citizens. Only intangible drilling costs, royalties, state and local taxes, and operating costs, exclusive of purchased injectants, are included in the calculation of state economic activity. Tubular steel products, injection and production equipment, purchased EOR injectants, corporate return on capital, and Federal taxes are all excluded from this definition of state economic activities. Royalties may be overstated to the extent that they are paid to the Federal government (i.e.,

Figure IV-1

Reserves and Production Response from EOR

Implemented Technology

A) Incremental Reserves by EOR Process

* No EOR projects were economic in analyzed reservoirs for oil prices below \$24/B.

B) Annual Production from EOR Reserves

Figure IV-2

Direct State and Local Revenues from EOR Production Implemented Technology

* No EOR projects were economic in analyzed reservoirs for oil prices below \$24/B.

on production from Federal lands). While the excluded elements undoubtedly aid Wyoming's citizens to some degree, a substantial portion of the benefits will be enjoyed by citizens of other states. However, to the extent that local manufacture or retail sales of these items provide economic benefits within Wyoming, injectants produced or manufactured in Wyoming are employed, or economic "multipliers" occur, the calculated economic effects are understated.

Figure IV-3 displays the total direct economic gains for the state over the oil price range analyzed. In all cases, operating costs could account for approximately 60% of these economic effects, state taxes could represent around 14%, intangible investment could be about 3%, and royalties could be about 21%. At \$24/B, incremental benefits to the state economy could exceed \$135 million. A substantial increase in economic activity occurs at oil prices above \$24/B; \$869 million and \$1.4 billion could be generated by EOR activities at the oil prices of \$28/B and \$32/B, respectively. At a historically high oil price of \$36/B, an estimated \$1.6 billion of statewide direct economic activity could be stimulated by EOR projects.

Successful EOR projects could create or maintain a substantial number of jobs statewide (Figure IV-4). The number of additional jobs attributable to new EOR projects could peak around the year 2010 at over 30 jobs per year at an oil price of \$24/B. At \$32/B, nearly 267 jobs per year could be created or maintained by implemented technology EOR projects in the peak year 2011. Total annual wages paid could peak between \$1.4 and \$12 million.

4. Effects on the National Economy and Budget

Increased oil recovery from EOR in Wyoming would benefit the nation as a whole. National benefits would accrue in several ways: increased Federal corporate and personal income tax revenues, replacement of oil imports, enhanced energy security, and a reduced foreign trade deficit. The addition of as many as 85 million barrels of reserves in Wyoming would expand the nation's proved reserve base. Since an additional barrel of domestic oil production serves to replace a barrel of imported oil, the nation's energy security would be enhanced through the implementation of EOR in Wyoming.

EOR activity in Wyoming contributes to the Federal treasury through personal and corporate income taxes (Figure IV-5A). At \$24/B, direct Federal revenues could be negative due to the Federal EOR tax credit. This credit, earned during the early stages of project implementation, is assumed to offset other profitable activities. At higher oil prices, the impact of increased production outweighs the decrease in Federal revenues and the tax credit begins to phase out. Increases in Federal revenues attributable to EOR could range from \$67 million at \$28/B to \$269 million at \$36/B over the life of the projects. Corporate income taxes would account for between 64% to 87% of this total, depending on the oil price, and personal income taxes would make up the remainder. Despite negative revenues in the early years, the application of EOR processes in Wyoming clearly could generate future revenues for the Federal treasury if the oil price should rise in the near future.

To the extent that increased domestic production replaces imported oil, the foreign trade deficit could be reduced by the direct value of imports avoided (incremental reserves multiplied by the effective wellhead oil price). Money formerly paid to oil exporting countries could instead circulate within the U.S. economy. At \$24/B, \$200 million in avoided imports could be generated by EOR projects in analyzed Wyoming reservoirs. At higher oil prices, the reduction in the trade deficit could be more substantial; nearly \$1.5 billion to \$2.6 billion in avoided imports could be generated by EOR activities at oil prices of \$28/B and higher (Figure IV-5B).

Figure IV-3

Direct State Economic Activity from EOR Production*

Implemented Technology

* To the extent that royalties go to the Federal government (i.e. fields on Federal lands), royalties as a portion of state economic activity may be overstated.

** No EOR projects were economic in analyzed reservoirs for oil prices below \$24/B.

Figure IV-4

Jobs and Wages from EOR Production Implemented Technology

Figure IV-5

National Impact of EOR Production

Implemented Technology

A) Direct Federal Revenues

* No EOR projects were economic in analyzed reservoirs for oil prices below \$24/B.

B) Imports Avoided*

* To the extent that 1 barrel of domestic oil replaces 1 barrel of imported oil, imports avoided measures the reduction in the foreign trade deficit.

** No EOR projects were economic in analyzed reservoirs for oil prices below \$24/B.

C. RECOVERY OF THE REMAINING MOBILE OIL RESOURCE

This section will discuss the application of currently available ASR processes in analyzed reservoirs throughout the state. These two distinct recovery technologies have been addressed separately to illustrate the potential benefits of each. However, since the resource target of these two technologies is mutually exclusive, both could be implemented in individual reservoirs in Wyoming, and the results could be independent and additive. Given the potential synergies in the simultaneous application of EOR and ASR technologies, the potential incremental reserves and associated economic benefits could be even greater than the sum of the two.

1. Production and Reserves

Depending on the oil price, ASR techniques applied in the analyzed Wyoming reservoirs could stimulate between 243 and 334 million barrels of incremental reserves (Figure IV-6A and Table IV-2A). ASR techniques are less costly to implement than EOR recovery processes, and therefore ASR incremental reserves are less sensitive to changes in the oil price. At the lowest oil price analyzed, \$16/B, over 243 million additional barrels could be recovered, nearly 73% of the 334 million barrels of oil that could be economically accessible at a historically high oil price of \$36/B.

This analysis evaluates three categories of ASR recovery processes: polymer flooding and profile modification, infill drilling, and combinations of infill drilling with polymer flooding or profile modification (combination processes). As shown in Figure IV-6A and Table IV-2A, infill drilling, both by itself and in combination with other processes, could play a predominant role in ASR, accounting for most of the incremental reserves at all analyzed oil prices. At oil prices of \$20/B and below, the combination processes could contribute from 165 to 205 million barrels of incremental reserves, while infill drilling alone could contribute 36 million to 69 million barrels of incremental reserves. The percentage of incremental reserves stemming from infill drilling, either alone or in combination with other processes, could range from 83% to 90% of the total potential depending on the oil price. As oil prices increase, infill drilling could become more economical since revenues increase along with oil prices. At \$28/B, 331 million barrels could be recovered by infill drilling techniques, accounting for 90% of ASR potential.

Table IV-2A

**Incremental Reserves from ASR by Process
Implemented Technology**
(Million Barrels)

Oil Price (\$/B)	Polymer Flooding and Profile Modification	Infill Drilling	Infill Drilling with Polymer Flooding or Profile Modification	Total
\$16	42	36	165	243
\$20	36	69	205	310
\$24	36	75	209	320
\$28	35	75	221	331
\$32	35	75	221	331
\$36	35	77	222	334

Table IV-2B

**Estimated Number of Economic ASR Projects by Process
Implemented Technology**
(Project Counts)

Oil Price (\$/B)	Polymer Flooding and Profile Modification	Infill Drilling	Infill Drilling with Polymer Flooding or Profile Modification	Total
\$16	13	9	27	49
\$20	10	10	36	56
\$24	10	12	37	59
\$28	9	12	40	61
\$32	11	12	40	63
\$36	10	13	41	64

Polymer flooding and profile modification, applied alone, could contribute between 35 and 42 million barrels of incremental reserves across the oil prices considered in this analysis. Incremental reserves from these processes could actually decline with rising oil price because improving economics allows them to be used in combination with more costly, but more prolific, infill drilling techniques. As the price of oil rises, thereby justifying the expense of infill drilling, reservoirs that were assigned to polymer or profile modification projects at lower oil prices could be reassigned to more prolific combination processes.

In this study, ASR projects are assigned initiation dates based on the time when that reservoir will reach its economic limit under conventional recovery techniques at the specific oil price considered. The economic limit is projected by a decline curve analysis, and the project start date is adjusted according to the availability of rigs to drill the required wells. Figure IV-6B displays the expected annual production from all ASR processes for oil prices of \$16/B and \$32/B. Annual ASR production at an oil price of \$16/B could rise gradually to 7.2 million barrels annually in the year 2020 and average about 3.0 million barrels per year over the 1993 to 2020 period. At an oil price of \$32/B, annual production could increase by over 9.8 million barrels and average over 4.2 million barrels per year over the 28 year period. To put the potential contribution of ASR into perspective, 4.2 million barrels per year would add about 5% to current Wyoming annual production.

2. Increases in State and Local Revenues

Figure IV-7 shows the expected growth in state revenues from ASR production and the proportional contributions of production and sales taxes to the total. Production tax receipts account for the largest portion of total state revenues from ASR over all oil prices considered. Production taxes could generate \$280 million of \$300 million in direct state and local revenues for Wyoming at \$16/B. At oil prices ranging from \$20/B to \$28/B, ASR activities could increase direct state and local revenues by \$490 million to \$720 million. At \$36/B, \$922 million could be generated by ASR processes, 95% of this from production taxes.

3. Effects on the State Economy

Figure IV-8 displays the total state economic activity associated with potential ASR production across the analyzed oil price range. Total state economic activity stimulated by ASR could range from

Figure IV-6

Reserves and Production Response from ASR

Implemented Technology

A) Incremental Reserves by ASR Process

B) Annual Production from ASR Reserves

\$1.9 billion at \$16/B to \$5.4 billion at \$36/B. At intermediate oil prices, state economic activity could total \$3.3 billion at \$20/B and \$4.5 billion at \$28/B. Operating costs could be the largest component of these increases in state economic activity, accounting for 24% to 31% of the total. These costs could approach \$1.3 billion at the \$36/B oil price. Intangible investment and royalties could be the next largest components of increased economic activity, averaging about 33% and 24%, respectively, of the total activity across all oil prices. State taxes could contribute the remaining 15%.

The implementation of ASR techniques in the analyzed Wyoming reservoirs could significantly contribute to employment in the state. Figure IV-9 displays the annual number of jobs that could be created or maintained by ASR projects. The annual trends in jobs created or maintained closely match the ASR production trends. At an oil price of \$16/B, jobs created or maintained could peak in the year 2020 at 178 annually. At \$32/B, the number of jobs created or maintained could peak in 2020 at over 380 per year. At this price, as much as \$17.1 million in wages could be paid in the peak employment year at the higher oil prices.

Figure IV-7

Direct State and Local Revenues from ASR Production Implemented Technology

Figure IV-8

Direct State Economic Activity from ASR Production*

Implemented Technology

* To the extent that royalties go to the Federal government (i.e. fields on Federal lands), royalties as a portion of state economic activity may be overstated

Figure IV-9

Jobs and Wages from ASR Production Implemented Technology

4. Effects on the National Economy and Budget

Figure IV-10 shows the national benefits of ASR production in Wyoming. Direct Federal revenues from ASR production could range from about \$589 million to more than \$2.2 billion over the oil price range analyzed. Nearly all of these revenues could stem from corporate income taxes. At moderate oil prices (\$20/B to \$28/B), \$860 million to \$1.4 billion of additional Federal revenues could be stimulated by ASR activities, over 95% of which could be from corporate income taxes (Figure IV-10A).

As the increased Wyoming production replaces oil imports, the U.S. trade deficit could be reduced and national security could be enhanced as the nation's vulnerability to future supply disruptions is diminished. Nearly \$6.0 billion to \$9.0 billion of avoided imports could be recirculated in the domestic economy as a result of ASR production at oil prices from \$20/B to \$28/B. At \$36/B, the trade deficit could be reduced by over \$11 billion (Figure IV-10B). To the extent that economic multipliers stimulate indirect effects, the recirculated funds could have an even greater impact of the overall economy.

D. CONCLUSIONS

The existing level of EOR and ASR technologies could make significant contributions to the reserves base and the Wyoming and national economies, as well as to domestic energy security. At a \$24/B oil price, EOR processes could add 8 million barrels to Wyoming reserves while ASR techniques could add 320 million barrels of incremental reserves. The application of currently available EOR and ASR technologies, in concert, could potentially add nearly 330 million barrels of incremental reserves at this price, adding nearly half to Wyoming's current proved reserves. As discussed in the next chapter, improved geoscientific understanding of reservoirs and enhanced process performance could increase these benefits if the required research can be cost effectively completed and transferred to the producers.

The state of Wyoming and its citizens stand to gain significantly from the increased production resulting from incremental reserve additions. Production increases could generate \$490 million to over \$1.0 billion in additional state and local revenues over the life of the EOR and ASR projects, assuming oil prices of \$20/B to \$32/B. Total state economic activity could be boosted by \$3.3 billion to \$6.3 billion over the same price range. Jobs could be created or maintained, and the national economy could benefit through decreased oil imports, reductions in the trade deficit, and increased Federal corporate and personal income tax revenues. Maximizing recovery of the known oil resource in Wyoming should therefore be

Figure IV-10

National Impact of ASR Production

Implemented Technology

A) Direct Federal Revenues

B) Imports Avoided*

* To the extent that 1 barrel of domestic oil replaces 1 barrel of imported oil, imports avoided measures the reduction in the foreign trade deficit.

an important goal for state and Federal policymakers. While these benefits could be available using currently available technology, the true potential could not be realized without an aggressive program of technology transfer. The estimated potential assumes wide application of these technologies. A collaborative technology transfer effort between the public and private sectors is critical to the attainment of these estimated benefits.

As shown in Figure IV-11, the oil that will remain in the analyzed reservoirs after production by both conventional operations and by wide-scale application of currently available EOR and ASR processes constitutes an important resource target for improved recovery technologies. Of the 3.9 billion barrels of immobile oil resource analyzed in this study, implemented technology EOR practices could produce an estimated 85 million barrels at an oil price of \$36/B, leaving over 3.8 billion barrels of remaining immobile oil in these reservoirs. Of the 2.3 billion barrels of unrecovered mobile oil in the reservoirs analyzed, implemented technology ASR practices could produce an estimated 330 million barrels at \$36/B, leaving 2.0 billion barrels in these reservoirs. The large size of the remaining resource clearly warrants a focused RD&D program that will test and speed the implementation of advanced technology to capture additional oil reserves.

Figure IV-11

V. BENEFITS OF INCREASED RECOVERY FROM THE KNOWN REMAINING OIL RESOURCE IN WYOMING WITH TECHNOLOGY ADVANCES

A. INTRODUCTION

While currently available enhanced oil recovery (EOR) and advanced secondary recovery (ASR) techniques could contribute substantially to the Wyoming reserves base, technological advances in these processes resulting from a concerted RD&D effort would have far more dramatic effects on the state's oil production. Development and wide-scale application of advanced methods could result in the recovery of a much greater portion of the remaining mobile and immobile oil resources in the state.

The present analysis evaluates the impact of advanced technology on oil recovery and the associated economic benefits. Evaluations of advanced technology EOR and ASR recovery potential in the state of Wyoming are presented separately. Given that the modeled advances in technology are conservatively defined, improvements in recovery processes resulting from research and development not envisioned in this report could add substantially to the estimated reserve potentials. However, well abandonments could limit access to the resource and increase project costs if EOR and ASR are not applied before conventional production ceases. Immediate actions are therefore necessary to realize the economic benefits of these advanced processes.

B. RECOVERY OF THE REMAINING IMMOBILE OIL RESOURCE

1. "Advanced" Technology Defined

Enhanced oil recovery processes, as currently applied, have severe limitations. Some current EOR techniques can only be applied to a limited number of reservoirs with properties which fall within a narrow range of suitable values (temperature, salinity, oil viscosity, etc.). The sweep efficiency of EOR processes is often relatively poor; only a small portion of the residual oil remaining in the previously waterflooded zone is contacted. Injectants are expensive, often approaching the value of the oil they are designed to recover, which places a burden on project economics. The National Petroleum Council (NPC) predicted gradual improvements in EOR performance and project economics as current processes are improved and tested in both the lab and the field. These advanced processes are predicted to gain operator

acceptance as the research and development efforts of oil companies, universities, geologic surveys, and the Federal government proceed and as field applications prove commercial viability. In this report, the IOGCC delayed the advanced technology availability date from the NPC's assumption of 1995 to the year 2000 to reflect the slower pace of RD&D activities in recent years caused by relatively low oil prices.

The major improvements in technology that are likely to impact enhanced oil recovery in Wyoming will be advances in chemical enhanced oil recovery applications. For advanced technology thermal recovery, the NPC modeled the effects of an improvement in the ability to inject steam at greater depths and into thinner, lower permeability reservoirs. For advanced technology chemical flooding, the NPC modeled the effects of increasing the salinity and temperature tolerance of injectants, thus enabling them to be applied in a larger number of reservoirs. This study also assumes that advances in chemical flood technology would result in improvements in injection rate, interfacial tension reduction, lower costs, and reduced chemical retention, thereby improving the recovery and economics of chemical projects. Additionally, the risk factors associated with current chemical and gas-miscible flooding are assumed to be substantially reduced by an RD&D effort.

2. Production and Reserves

With technology advances, EOR could stimulate a substantial amount of incremental reserves at oil prices from \$20/B to \$36/B. (EOR was not found to be economic at prices below \$20/B, even with technology advances.) Figure V-1 and Table V-1A compare the incremental reserves which could be added by advanced technology EOR with those added under the implemented technology EOR. The principal benefit of advanced technology would be to make additional reserves available at lower oil prices in Wyoming; advanced EOR technology could add 118 million barrels of incremental reserves at \$20/B, all of which is due to technology advances. At \$24/B, advances in EOR technology could add over 200 million barrels of incremental reserves, for a total of over 210 million barrels of potential reserves from EOR. At historically high oil prices (\$36/B), advanced technology EOR processes could increase implemented technology potential reserves by over 320 million barrels for a total of nearly 410 million barrels, 53% of Wyoming's 1991 proved reserves.

The potential incremental reserves contributed by each of the advanced EOR processes considered in this analysis are also shown in Figure V-1. At \$20/B, advanced chemical flooding could be the primary source of incremental reserves, potentially generating 105 million barrels of oil. At the same price,

Figure V-1

Incremental Reserves by EOR Process Implemented Technology vs. Advanced Technology

* No EOR projects were economic in analyzed reservoirs for oil prices below \$20/B.

thermal recovery could generate about 13 million barrels of incremental reserves. At \$28/B, advanced CO₂-miscible flooding could contribute about 28 million barrels of oil, more than double the recovery possible from this process under implemented technology. Advanced chemical processes could contribute nearly 190 million barrels to total incremental reserves at this oil price, 150 million barrels of which could be due to technology advances attainable through RD&D. Thermal techniques could contribute 130 million barrels at \$28/B. Between \$28/B and the upside potential at \$36/B, there would be little reserves response to increased price; CO₂-miscible and chemical projects could attain 80% and 98%, respectively, of their upside potential at \$28/B, while thermal techniques could stimulate only 52 million barrels of additional incremental reserves in response to an \$8/B increase in price.

The number of EOR projects that could be initiated in Wyoming is displayed by process type and by oil price in Table V-1B. Advances in EOR technology could increase recovery by making existing techniques more efficient and expanding the scope of processes to new geologic settings. The number of economic CO₂-miscible projects due to technological advances does not change with the price of oil. However, the incremental reserves attributable to this technique more than double. Advanced CO₂-miscible flooding is more efficient than the implemented technology process in the reservoirs where both

Table V-1A

**Incremental Reserves from EOR by Process
Implemented Technology vs. Advanced Technology
(Million Barrels)**

Oil Price (\$/B)	CO ₂ -Miscible		Chemical		Thermal		Total	
	Implemented	Advanced*	Implemented	Advanced*	Implemented	Advanced*	Implemented	Advanced*
\$16	0	0	0	0	0	0	0	0
\$20	0	0	0	105	0	13	0	118
\$24	0	0	8	185	0	27	8	212
\$28	13	28	39	189	0	130	52	347
\$32	18	33	39	192	26	159	83	384
\$36	20	35	39	191	26	182	85	408

* This is the total reserves with advanced technology -- implemented technology plus the increment due to technology advances.

Table V-1B

**Estimated Number of Economic EOR Projects by Process
Implemented Technology vs. Advanced Technology
(Project Counts)**

Oil Price (\$/B)	CO ₂ -Miscible		Chemical		Thermal		Total	
	Implemented	Advanced	Implemented	Advanced	Implemented	Advanced	Implemented	Advanced
\$16	0	0	0	0	0	0	0	0
\$20	0	0	0	6	0	1	0	7
\$24	0	0	1	13	0	2	1	15
\$28	2	2	2	14	0	3	4	19
\$32	3	3	2	15	1	4	6	22
\$36	4	4	2	14	1	7	7	25

may be applied economically. The number of chemical and thermal projects in the advanced technology case far exceeds the number in the implemented technology case. The additional incremental reserves due to advanced technology could largely result from extending these processes to reservoir settings that could not be developed, either technically or economically, under implemented technology conditions.

Figure V-2 shows the expected annual EOR production for oil prices of \$24/B and \$32/B for both the implemented and advanced technology cases. At each price significant increases in annual production could be attainable through technology advances. At \$24/B, Wyoming production could total about 6.4 million barrels per year by the year 2019 as a direct result of advanced EOR, nearly all of which would be due to technology advances. At \$32/B, advanced technology EOR could generate as much as 11.6 million barrels in the year 2017. At this price, the peak production level under advanced technology would be over three times that under implemented technology.

3. Effects on State Revenues and Economic Activity

At all oil prices considered in this analysis, the direct revenues to the state of Wyoming attributable to EOR could significantly increase under advanced technology conditions (Figure V-3A). Similar to the implemented technology case, production taxes could make up over 85% of the state's total direct revenues and sales tax receipts could contribute the remaining 15%. At the \$20/B, state revenues from advanced technology EOR could amount to over \$180 million, all of which would be attributable to technology advances. At \$24/B, advances in EOR technology could generate incremental direct state and local revenues from EOR production of over \$345 million, for a total advanced technology potential of \$360 million. At the higher oil prices of \$28/B to \$36/B, direct state revenues from advanced technology EOR production could range from \$680 million to \$1.0 billion, over 70% of which could be due to advances in EOR technology.

Direct state economic activity generated by Wyoming EOR could also be enhanced by advanced technology. Figure V-3B displays the total potential incremental direct economic benefits to the state for both the implemented and advanced technology cases. The distribution of total economic benefits among the contributing components under advanced technology is similar to the trend shown for the implemented technology case. At \$20/B, advanced EOR technology could stimulate about \$1.6 billion of incremental state economic gain, all of which is due to technology advances. At a \$24/B oil price, advanced technology EOR activity could increase the state's economic activity by \$3.1 billion over implemented

Figure V-2

Annual Production from EOR Reserves

Implemented Technology vs. Advanced Technology

A) At \$24/B

B) At \$32/B

Figure V-3

State Impact of EOR Production

Implemented Technology vs. Advanced Technology

A) Direct State and Local Revenues

* No EOR projects were economic in analyzed reservoirs for oil prices below \$20/B

B) Direct State Economic Activity

* To the extent that royalties go to the Federal government (i.e. fields on Federal lands), royalties as a portion of state economic activity may be overstated.

** No EOR projects were economic in analyzed reservoirs for oil prices below \$20/B.

technology for a total potential of \$3.2 billion. At \$28/B, the direct state-wide economic gain could increase from \$900 million under implemented technology to \$6.1 billion with full advanced EOR technology development; the difference reflects the impact of a successful RD&D effort. The state of Wyoming could accrue significant benefits from the results of applying advanced EOR technology at all of the oil prices considered in this analysis.

Advances in technology could have a substantial impact on the state's employment. At \$24/B, the development of advanced technology could create or maintain over 500 jobs per year by 2020, nearly all of which would be attributable to technology advances (Figure V-4A). At an oil price of \$32/B, the jobs created or maintained under advanced technology conditions could exceed those in the implemented case by about 700 per year, with annual totals of over 900 jobs per year (Figure V-4B). Wages paid could total over \$40 million per year at the highest oil price considered.

4. Effects on the National Economy and Budget

Increased oil recovery in Wyoming through EOR processes could significantly benefit the nation in the areas of enhanced energy security, imports avoided, a reduced trade deficit, and expanded direct revenues to the Federal treasury. The potential benefits are even more pronounced with the development of advanced technology. Up to 408 million barrels of crude oil could be added to proved reserves due to advanced EOR technology, 323 million barrels more than the incremental reserves estimated under the implemented case.

Revenues to the Federal treasury, in the form of corporate and personal income taxes, could grow along with the increase in reserves as a result of advanced technology (Figure V-5A). At moderate oil prices of \$20/B to \$28/B, \$30 million to \$200 million in additional direct Federal revenues could be generated by technology advances. Total Federal revenues from advanced technology at these oil prices could range from \$30 million to over \$260 million. At \$36/B, \$930 million of the nearly \$1.2 billion in total additional direct Federal revenues (over 77%) could be attributed to advances in EOR technology.

The foreign trade deficit could be reduced by the value of imports avoided due to increased EOR production. At oil prices of \$20/B to \$28/B, production due to technology advances could result in \$2.3 billion to \$7.2 billion in imports avoided (Figure V-5B). The total potential of \$2.3 billion to \$8.7 billion in avoided imports at these oil prices would represent a significant amount of money being recirculated

Figure V-4

**Annual Jobs and Wages from EOR Production
Implemented Technology vs. Advanced Technology**

A) At \$24/B

B) At \$32/B

Figure V-5

National Impact of EOR Production

Implemented Technology vs. Advanced Technology

A) Direct Federal Revenues

* No EOR projects were economic in analyzed reservoirs for oil prices below \$20/B.

B) Imports Avoided*

* To the extent that 1 barrel of domestic oil replaces 1 barrel of imported oil, imports avoided measures the reduction in the foreign trade deficit.

** No EOR projects were economic in analyzed reservoirs for oil prices below \$20/B

within domestic economy rather than abroad, thereby reducing the trade deficit. At \$36/B, the trade deficit could be reduced by nearly \$13 billion, 80% of which is attributable to the effects of a successful RD&D effort.

C. RECOVERY OF THE UNRECOVERED MOBILE OIL RESOURCE

1. "Advanced" Technology Defined

The unrecovered mobile oil (advanced secondary recovery) advanced case analysis, designed to reflect the potential technological improvements possible from a focused RD&D program in geological reservoir characterization, is conducted in a manner consistent with the implemented technology case analysis. A major assumption is that RD&D will allow geologic reservoir characterization techniques to be widely applied, resulting in infill drilling that is targeted only into those portions of the reservoir where project economics will allow drilling at closer spacings. This will improve the project economics of ASR resulting in more activity and much greater recovery under the advanced case than would be possible under the reservoir-wide, blanket drilling program assumed in the implemented technology case. Heterogeneous portions of reservoirs contain a proportionally larger amount of unrecovered mobile oil that is trapped in isolated compartments or bypassed by the injection fluids in conventional recovery operations. By contrast, the more homogenous portions of reservoirs exhibit more efficient conventional recovery and require less intensive drilling. In this study, infill drilling potential is evaluated by dividing each reservoir into two parts, a more continuous (homogeneous) segment and a less continuous (heterogeneous) one. The economic recovery potential is evaluated independently in each segment, and the closest economic well spacing for each segment is independently selected.

The improved recovery methods discussed in this analysis could have a substantial impact on ASR reserve additions. Additional recovery could be stimulated as the chemical composition of polymer injectants is improved to withstand higher reservoir temperatures (up to 250° F) and/or formation salinities (up to 200,000 parts per million). These improvements would increase the marginal impact of the profile modification and polymer flooding projected under the implemented technology case whether they are applied alone or in combination with infill drilling. Additional benefits are estimated from the reduction of the associated risk (modeled as a reduction in hurdle rates with technology advances as discussed in Chapter III) of ASR processes as currently implemented.

2. Production and Reserves

The development of advanced technology ASR methods through RD&D could significantly increase Wyoming's oil reserves. The incremental reserves due to advances in ASR technology could range between 113 million to 186 million barrels in the analyzed Wyoming reservoirs (Figure V-6). Total incremental reserves for advanced technology ASR could range from 390 million to 520 million barrels over the life of the ASR projects. At \$24/B, over 450 million barrels of incremental oil could be produced, 60% of Wyoming's current proved reserves.

A substantial amount of incremental reserves could be generated by ASR at low prices. Over 390 million barrels could be economically producible at \$16/B, 148 million barrels of which would be attributable to technology advances. Total incremental reserves for each corresponding \$4/B increment above \$16/B could average about 25 million barrels, indicating the relative insensitivity of ASR to changing oil prices. Between 25% and 35% of the incremental reserves from ASR at oil prices ranging from \$20/B to \$36/B would be due to the impact of a successful RD&D effort.

Figure V-6

Incremental Reserves by ASR Process Implemented Technology vs. Advanced Technology

Table V-2A shows the distribution of incremental reserves by ASR process. Infill drilling in combination with profile modification or polymer flooding could be the most prolific advanced technology recovery method, contributing from 50% to over 60% of the total incremental reserves. Infill drilling, applied alone, could generate between 5% and 6% of total incremental reserves potential from ASR. Polymer flooding and profile modification processes could contribute between 12% to 23% of the total recovery in the advanced technology case.

Geologically targeted infill drilling, by itself or in combination with other processes, could generate incremental reserves that are between 51% to 55% higher than those estimated in the implemented technology, blanket infill drilling case at all oil prices. Technology advances lead to significant improvements in the effectiveness of infill drilling techniques. An improved understanding of reservoir architecture and the nature of heterogeneity would allow wells to be economically justified at much closer spacing than is currently possible. As these new wells contact additional volumes of oil, ultimate recovery would be improved. The ability to target infill wells would eliminate the unnecessary wells that would be drilled under a blanket infill drilling program. Targeting infill wells would reduce the front-end investment for each project undertaken, making some otherwise uneconomic projects cost-effective, even at low oil prices. As observed in the implemented technology case, the contribution of polymer flooding and profile modification to total incremental reserves could be fairly constant across the oil prices analyzed, adding 56 to 86 million barrels of incremental reserves from analyzed Wyoming reservoirs.

Table V-2B shows the estimated number of economic ASR projects for both the implemented and advanced technology cases. The number of projects using infill drilling alone is considerably smaller under advanced technology than under implemented technology. This is largely due to improved technology and economics which permit infill drilling to be combined with polymer flooding or profile modification. Much of the benefits of advanced technology are due to the ability to economically implement the more costly, but more prolific, combination processes in many reservoirs.

Figure V-7 displays the projected annual production that could result from ASR technology advances for oil prices of \$16/B and \$32/B from the analyzed Wyoming reservoirs. A significant amount of oil could be added to the state's production over the next 20 years. At \$16/B, advances in technology could increase implemented technology ASR production by 4.0 million barrels per year for a total of 11.2 million barrels annually by the year 2020. At \$32/B, peak production could exceed 14.9 million barrels

Table V-2A

**Incremental Reserves from ASR by Process
Implemented Technology vs. Advanced Technology
(Million Barrels)**

Oil Price (\$/B)	Polymer Flooding and Profile Modification		Infill Drilling		Infill Drilling and Polymer Flooding or Profile Modification		Total	
	Implemented	Advanced*	Implemented	Advanced*	Implemented	Advanced*	Implemented	Advanced*
\$16	42	86	36	22	165	283	243	391
\$20	36	54	69	21	205	348	310	423
\$24	36	54	75	18	209	384	320	456
\$28	35	58	75	20	221	388	331	466
\$32	35	60	75	26	221	394	331	480
\$36	35	56	77	33	222	431	334	520

* This is the total reserves with advanced technology -- implemented technology plus the increment due to technology advances.

Table V-2B

**Estimated Number of Economic ASR Projects by Process
Implemented Technology vs. Advanced Technology
(Project Counts)**

Oil Price (\$/B)	Polymer Flooding and Profile Modification		Infill Drilling		Infill Drilling and Polymer Flooding or Profile Modification		Total	
	Implemented	Advanced	Implemented	Advanced	Implemented	Advanced	Implemented	Advanced
\$16	13	13	9	5	27	41	49	59
\$20	10	11	10	5	36	48	56	64
\$24	10	11	12	4	37	50	59	65
\$28	9	12	12	5	40	51	61	68
\$32	11	14	12	6	40	51	63	71
\$36	10	12	13	8	41	51	64	71

Figure V-7

Annual Production from ASR Reserves

Implemented Technology vs. Advanced Technology

A) At \$16/B

B) At \$32/B

per year; the 4.0 million barrel per year increase over implemented technology potential could be attainable due to advances in ASR technology. The peak production rate at \$32/B would total nearly 15% of Wyoming's 1991 oil production levels.

3. Effects on State Revenues and Economic Activity

ASR technology advances could significantly increase direct state and local tax revenues from production taxes and oil industry-related sales taxes in Wyoming across the analyzed oil price range (Figure V-8A). At moderate oil prices (\$20/B to \$28/B), technology advances could increase implemented technology potential direct state revenues by \$180 million to \$300 million, for a total potential of \$670 million to over \$1.0 billion in direct state revenues. At \$36/B, \$540 million (37%) of the \$1.5 billion in potential states revenues could be stimulated by ASR technology advances. As in the implemented technology case, the revenue could mostly be generated from production taxes. These taxes account for over 90% of the direct state tax revenues added at each of the price levels considered in this analysis.

In addition to the increases in state and local revenues, Wyoming could benefit from the stimulation of economic activity within the state. Advanced technology ASR could stimulate \$3.2 billion to \$9.7 billion in economic activity, depending on the oil price. The increase of \$1.2 billion to \$4.3 billion over implemented technology direct state economic activity would be attributable to technology advances. Figure V-8B displays the components of this increase. Operating costs, royalties, and intangible investment from ASR projects could all make substantial contributions to the state's economic activity. Direct state tax revenues could comprise the smallest portion of the increase.

Figure V-9 presents estimates for the number of jobs that could be created or maintained by the application of advanced ASR technology in Wyoming. As the price of oil rises, the total number of jobs created or maintained could grow substantially, with the incremental jobs stimulated directly by advanced technology accounting for much of the increase. At \$16/B, nearly 92 jobs per year could be created or maintained due to technology advances, for a total potential of almost 270 jobs annually by the year 2020. At \$32/B, 210 of the 591 potential jobs per year in the year 2020 would be attributable to advances in ASR technology.

Figure V-8

State Impact of ASR Production

Implemented Technology vs. Advanced Technology

A) Direct State and Local Revenues

B) Direct State Economic Activity*

* To the extent that royalties go to the Federal government (i.e. fields on Federal lands), royalties as a portion of state economic activity may be overstated.

Figure V-9

Annual Jobs and Wages from ASR Production

Implemented Technology vs. Advanced Technology

A) At \$16/B

B) At \$32/B

4. Effects on the National Economy and Budget

The development of advanced technology for the recovery of the known ASR resource in the state of Wyoming could also benefit the nation. Figure V-10A shows a significant increase in the incremental revenues to the Federal treasury from corporate and personal income taxes due to technology advances. At oil prices ranging from \$20/B to \$28/B, direct Federal revenues could increase by \$180 million to \$330 million over implemented technology revenues due to technology advances for a total potential of \$1.0 billion to \$1.8 billion. At \$36/B, advanced technology ASR projects could generate over \$3.0 billion in incremental direct Federal revenues, 27% of which would be attributable to the results of a successful RD&D effort. Most of the increase in revenues would stem from corporate income taxes.

Advances in ASR technology could stimulate an additional 113 million to 186 million barrels of incremental reserves. The total potential of 390 million to 520 million barrels of crude oil reserves could significantly replace imports, increasing the nation's energy security and reducing the trade deficit by the value of the avoided imports. Money spent on increased domestic production would circulate within the U.S. economy rather than abroad. At moderate oil prices, \$8.2 billion to nearly \$16 billion in imports avoided could be generated by advanced technology ASR projects, 25% to 30% of which would be attributable to technology advances. At \$36/B, over \$6.5 billion of avoided imports could be generated by technology advances, for a total potential of over \$18 billion in avoided imports (Figure V-10B).

D. CONCLUSIONS

As discussed in Chapter IV, currently available EOR and ASR technologies have the potential to significantly increase reserves and provide substantial economic benefits to operators, the states, and the nation. An aggressive and efficient technology transfer program in both the public and private sectors would bring these available technologies to operators and expedite their application in the field. At an oil price of \$20/B, implemented technology EOR and ASR process could contribute 310 million barrels of oil to Wyoming's reserves base. At \$28/B, potential incremental reserves could reach over 380 million barrels.

Advances in technology could significantly increase the potential reserves and associated economic benefits arising from application of implemented technology EOR and ASR. Technology advances could increase implemented technology incremental reserves by over 230 million barrels of oil at an oil price

Figure V-10

National Impact of ASR Production

Implemented Technology vs. Advanced Technology

A) Direct Federal Revenues

B) Imports Avoided*

* To the extent that 1 barrel of domestic oil replaces 1 barrel of imported oil, imports avoided measures the reduction in the foreign trade deficit.

of \$20/B. The total potential reserves at this price, over 540 million barrels, is more than 71% of Wyoming 1991 proved reserves. At an oil price of \$28/B, technology advances could add 430 million barrels of incremental reserves for a total EOR and ASR reserves potential of over 810 million barrels. If this potential were to be realized, advanced technology EOR and ASR would more than replace Wyoming 1991 proved reserves.

The activities associated with advanced technology EOR and ASR would generate substantial direct state tax revenues. At an oil price of \$20/B, \$360 million of the \$850 million of potential direct state revenues are attributable to technology advances. At \$28/B, over 50% (\$857 million) of the \$1.7 billion in total potential state revenues could be due to advances in technology.

The potential benefits estimated in this analysis will not be possible, however, without effective technology transfer and RD&D programs. Aggressive technology transfer needs to be undertaken by all oil-related entities (operators, producer associations, research universities, state geologic surveys, and state and Federal government agencies) in order to ensure that currently available technologies are disseminated in the oil patch and widely applied in the field. The significant additional benefits derived from technology advances clearly warrant a focused RD&D program to improve advanced oil recovery technologies.

A collaborative effort between the public and private sectors is essential to pool resources and expertise while leveraging risk. Operators, oil companies, research universities, and state geologic surveys need to join with state and local governments and the Federal government to identify the highest priority problems in reservoirs with the largest remaining resources and the greatest threat of abandonment. A focused RD&D effort targeting the identified problems then needs to be undertaken. An RD&D effort alone is not enough, however; the newly developed technologies need to be transferred to the field for wide-scale demonstration and application. The Department of Energy's Program Opportunity Notice (PON) process is currently applying some of these concepts. The PON process targets particular classes of reservoirs with the largest potential resource and the greatest threats of abandonment. Near- and mid-term RD&D efforts, jointly funded by the Federal government and private industry, are directed towards the producing problems of these reservoirs. The results, once successfully developed and demonstrated, are to be transferred to other operators facing similar producing conditions. While they are a start, efforts like the PON process are not enough. A more aggressive and focused collaborative RD&D effort will

greatly increase domestic production, enhance national energy security, reduce imports, and increase economic benefits associated with oil recovery.

Even after application of advanced technology EOR and ASR, a significant portion of the oil resource will remain unrecovered in the analyzed reservoirs (Figure V-11). At the improbably high oil price of \$36/B, total ASR reserves potential would be 520 million barrels while EOR reserves potential would total 410 million barrels. If this reserves potential were realized, 1.8 billion barrels of mobile oil (78% of the mobile oil target) and 3.5 billion barrels of immobile oil (90% of the immobile oil target) would remain in analyzed reservoirs. In addition, 7.2 billion barrels of remaining oil not included in this analysis, along with any newly discovered oil, would still be unrecovered after the application of advanced technology EOR and ASR. The 12.5 billion barrels of known remaining oil-in-place is the target for further advances in EOR and ASR technologies.

Figure V-11

Wyoming Remaining Oil Resource After Advanced Technology Recovery

VI. AN EVALUATION OF WYOMING STATE TAX INCENTIVES

A. INTRODUCTION

Previous studies sponsored by the IOGCC and various states have indicated that focused state tax incentives can be simultaneously beneficial to operators and the state economy. Relief of state production taxes on incremental EOR and ASR production could enhance profitability of marginal improved oil recovery projects, thus significantly increasing state-wide reserves potential. The resulting higher level of investments and production could stimulate new state tax revenues and statewide economic activity, more than offsetting the foregone revenues on improved recovery projects that would have been implemented without the incentive. Therefore, appropriately designed tax incentives offer the promise of "non-zero-sum" gains, where producers, state treasuries, and the national economy benefit due to the resulting increased oil production from known reservoirs.¹

Wyoming levies a severance tax on oil production of 7.5% of the revenues from production. Stripper wells (producing less than 10 barrels of oil per day) are subject to a 5.5% severance tax. In addition, oil operators must pay a conservation tax of 0.02% of revenues from production. Currently, EOR projects are exempt from a 2.0% state excise tax for the first five years of a project. As this tax incentive expires at the end of 1994, it was not included in this analysis. The state of Wyoming does not levy a corporate income tax. This chapter assesses the impact of one state tax incentive option for Wyoming — relief of severance taxes on incremental production until project payback (i.e., until cumulative cash flow from the project exceeds zero).

This incentive design was shown to be effective in previous IOGCC studies for the states of Oklahoma and New Mexico.^{1,2} Further, this incentive is self-limiting, directing economic stimulus to projects that require tax relief and away from projects that would be profitable without the incentive. The size and term of the incentive is directly related to the magnitude of each project's initial investment and

¹ Interstate Oil and Gas Compact Commission, *The Potential of Enhanced Oil Recovery in Oklahoma*, April 1987.

² Interstate Oil and Gas Compact Commission, *The Potential of Enhanced Oil Recovery by Carbon Dioxide Flooding in New Mexico*, December 1986.

early operating costs. The proposed incentive provides for lower costs and risks to the state while providing operators with early benefits that are critically important to marginal projects.

Any proposed state incentive must take into account the FY91 Federal EOR tax credit. This provides a credit against Federal income tax equal to 15% of all qualified EOR costs (tangible property investments, intangible drilling and development costs, and purchase costs of tertiary injectant) on projects that began or were significantly expanded after December 31, 1990. The tax credit is contingent upon prior professional certification that the EOR project is capable of producing "more than an insignificant increase" in ultimate recovery. Because the goal of the incentive is to make the application of EOR techniques economic at lower oil prices, the incentive is gradually phased out at oil prices above \$28/B. For every \$1/B that the average bench mark price for the preceding year exceeds \$28/B, the incentive is reduced 2.5 percentage points for the subsequent year, completely phasing out the incentive at an oil price of \$34/B.

The analysis considers three key factors important to the state of Wyoming:

- Incremental reserves and production;
- Direct state tax revenues from production and sales taxes; and
- Overall in-state economic activity, including wages and benefits paid.

Other economic benefits which accrue to citizens of other states, Federal tax revenues and overall gains in domestic economic activity, are also assessed.

B. RESERVES AND PRODUCTION

Under the implemented technology case, the proposed tax incentive could increase recovery from known Wyoming reservoirs by as much as 51 million barrels over the reserves possible with the current tax structure (base case) (Table VI-1 and Figure VI-1A). Because ASR projects are less sensitive to price changes than EOR projects, the incentive impacts EOR more than ASR. Further, the effect of the tax credit is concentrated at lower oil prices. At \$20/B, no EOR projects would be economic under the current tax structure. With a tax incentive, nearly 40 million barrels of incremental EOR reserves could be stimulated. At oil prices of \$24/B and \$28/B, over 40 million barrels of oil could be added to proved

reserves as a direct result of a state tax incentive for EOR projects. At higher oil prices, the impact of the incentive on EOR reserves would be smaller; 13 million to 20 million barrels of incremental reserves could be stimulated by the incentive. ASR reserves potential could increase by less than 10 million barrels of oil over the current tax structure potential across the range of analyzed oil prices.

A tax incentive combined with technology advances could generate much more substantial benefits in terms of additional oil recovery (Figure VI-1B). The tax incentive would be most effective in stimulating incremental EOR reserves at oil prices less than \$32/B. At \$20/B, the tax incentive could stimulate an additional 76 million barrels of EOR reserves over base case potential. At \$24/B and \$28/B, 110 million barrels and 73 million barrels of incremental reserves, respectively, could be stimulated by the tax incentive. At these moderate oil prices (\$20/B to \$28/B), the combined effect of technology advances and the tax incentive could generate between 190 million and 370 million barrels of incremental reserves over the implemented technology base case. The total potential with technology advances and the tax incentive at these prices, could range from 190 million barrels to 420 million barrels. As with implemented technology, the tax incentive does not have as significant an impact on advanced technology ASR reserves. Between 4 million and 16 million barrels of incremental oil could be added to base case reserves due to the tax incentive across the range of analyzed oil prices.

C. DIRECT STATE TAX REVENUES AND ECONOMIC ACTIVITY

As discussed in previous chapters, EOR and ASR projects could contribute significant revenues to the state treasury in the form of production taxes and state sales taxes on materials and equipment purchased. With a focused state tax incentive, incremental revenues from marginally economic projects could also flow to the state. These revenues, however, would be levied at the cost of some revenues foregone in projects already economic at the respective oil price. Production tax revenues would be lost on those projects which would have been profitable without the tax incentive. In some cases, the increase in tax revenues from new projects which are stimulated by the incentive would not be sufficient to offset revenues that may be lost. However, it is possible to design the tax incentive to stimulate the maximum incremental reserves at the minimum cost to Wyoming's taxpayers.

Figure VI-2A shows the total state revenues that could accrue from economically viable, implemented technology EOR and ASR projects under the analyzed state tax incentive. At oil prices of \$28/B and lower, implementing a tax incentive could increase the direct state revenues resulting from EOR

Figure VI-1

Impact of Tax Incentive on EOR and ASR Reserves

Base Case vs. Incentive Case

A) Implemented Technology

* At oil prices above \$28/B, the Federal EOR tax credit decreases by 2.5% for each \$1 over the \$28/B oil price; complete phaseout occurs at an oil price of \$34/B.

B) Advanced Technology

* At oil prices above \$28/B, the Federal EOR tax credit decreases by 2.5% for each \$1 over the \$28/B oil price; complete phaseout occurs at an oil price of \$34/B.

Table VI-1

Effect of Tax Incentive on Incremental Reserves
(Million Barrels)

Oil Price (\$/B)	Tax Structure	Implemented Technology			Advanced Technology*		
		EOR	ASR	Total	EOR	ASR	Total
\$16	Base	0	243	243	0	391	391
	Incentive	0	243	243	0	400	400
\$20	Base	0	310	310	118	423	541
	Incentive	39	315	354	194	427	621
\$24	Base	8	320	328	212	456	668
	Incentive	50	326	376	322	464	786
\$28	Base	52	331	383	347	466	813
	Incentive	96	336	432	420	482	902
\$32	Base	83	331	414	384	480	864
	Incentive	96	338	434	434	488	922
\$36	Base	85	334	419	408	520	928
	Incentive	106	340	446	455	530	985
Increment due to Financial Incentives							
\$16		0	0	0	0	9	9
\$20		39	5	44	76	4	81
\$24		42	6	48	110	8	118
\$28		44	5	49	73	16	89
\$32		13	7	20	50	8	58
\$36		21	6	27	47	10	57

* This is the total reserves under advanced technology -- implemented technology plus the increment due to technology advances.

activities. Base case state revenue potential could be increased by \$10 million to \$40 million due to the tax incentive over this price range, with the largest increase occurring at \$24/B. A state tax incentive for EOR projects at oil prices of \$28/B and lower could increase state tax revenues while also stimulating an additional 39 million to 44 million barrels of incremental reserves over the implemented technology base case potential. At higher oil prices, the incentive could result in a decrease from the base case potential revenues. This decrease could range from \$6 million to \$33 million, depending upon the oil price.

With advances in technology, productivity and project economics tend to improve; fewer projects, therefore, would require the tax incentive to be profitable. As a result, combined application of a tax incentive with technology advances could lead to a decrease in state and local revenues across the analyzed price range for advanced technology EOR and ASR activities (Figure VI-2B). For EOR, the decrease could range from \$30 million to \$270 million, and for ASR, it could range from \$25 million to over \$60 million.

The tax incentive could, however, increase the general level of economic activity (as defined in Chapters IV and V) within Wyoming, despite decreasing tax revenues. As with other activities, Wyoming may wish to "invest" in a better economic future by foregoing some immediate revenues in order to generate business activity within the state. As noted before, the incentive could be much more effective with EOR than ASR.

Table VI-2 shows the potential Wyoming state and local revenues and direct economic activity that could result from the analyzed tax incentive on EOR projects. There could be a considerable payoff in terms of state economic activity for advanced EOR at lower oil prices. At \$20/B, Wyoming could enjoy an additional \$940 million in economic activity by foregoing \$32 million in taxes (a 29 to 1 ratio). At \$24/B, state economic activity due to EOR production could increase by \$1.5 billion by foregoing \$34 million in taxes (a 45 to 1 ratio). Even as oil prices reach \$28/B, nearly six times the foregone state revenues could be generated in state economic activity due to the analyzed tax incentive on EOR (\$155 million of foregone revenues for \$925 million in economic activity). Thus, in the larger perspective, Wyoming may wish to target the incentive to EOR projects at oil prices less than \$32/B, but also actively support the development of technology advances in order to reap additional benefits in state economic activity.

Figure VI-2

Impact of Tax Incentive on Direct State and Local Revenues

Base Case vs. Incentive Case

A) Implemented Technology

B) Advanced Technology

Table VI-2

**Summary of State Economic Benefits and Trade-offs of
Analyzed Tax Incentive on EOR in Wyoming***

Oil Price (\$/B)	Tax Structure	Implemented Technology		Advanced Technology	
		Direct State and Local Revenues (\$ Millions)	Direct State Economic Activity (\$ Millions)	Direct State and Local Revenues (\$ Millions)	Direct State Economic Activity (\$ Millions)
\$16	Base	0	0	0	0
	Incentive	0	0	0	0
\$20	Base	0	0	181	1,555
	Incentive	30	443	149	2,497
\$24	Base	17	136	362	3,212
	Incentive	57	678	328	4,765
\$28	Base	125	869	678	6,076
	Incentive	136	1,443	523	7,001
\$32	Base	206	1,419	845	7,311
	Incentive	153	1,585	627	7,958
\$36	Base	235	1,588	1,014	8,423
	Incentive	192	1,930	744	9,153

* The economic effects of a tax incentive on EOR only are shown here; because ASR is less sensitive to the price of oil than EOR is, the economic effects of a tax incentive on ASR are marginal.

D. DIRECT FEDERAL REVENUES AND NATIONAL ECONOMIC ACTIVITY

The analyzed tax incentive on incremental EOR and ASR production from Wyoming reservoirs could add substantially to the Federal treasury and the national economy. The stimulated projects could increase Federal income tax payments by operators and their employees. Further, the additional spending for drilling, field equipment, and injectants provides new incremental spending in the United States, payments that otherwise would have been made to purchase and import foreign oil.

Direct Federal revenues could increase at nearly all oil prices and technology scenarios considered in this analysis with the exception of advanced ASR technology at an oil price of \$16/B. The increased production and resulting jobs which are maintained or created by the recovery operations could produce significant Federal taxes. The impact of the tax incentive would be larger on EOR activities than on ASR activities, as ASR potential is less sensitive to changes in oil price.

Table VI-3 shows the potential Federal revenues and national gains that could be generated from the analyzed tax incentive on EOR projects. At oil prices of \$20/B to \$28/B under implemented technology, total Federal revenues from EOR could increase by \$3 million to \$46 million due to the analyzed tax incentive. Under advanced technology, \$22 million to \$118 million of the incentive case potential at these prices could be attributed to EOR activity.

Likewise, overall national economic activity, as measured by the direct value of the avoided imports (reserves multiplied by the effective wellhead price of oil), could increase as a direct result of the analyzed state tax incentive. The effect would be greatest for EOR at low oil prices (Table VI-3). Incremental domestic production could offset payments that would be made for imported oil and therefore could result in large gains to the nation's economy. The largest increases due to the proposed incentive could occur at an oil price of \$24/B for implemented and advanced technology EOR activities (\$1.0 billion to \$2.0 billion).

E. CONCLUSIONS

A tax incentive for Wyoming operators, in the form of tax relief on incremental production, could improve the economic viability of EOR projects and thus increase reserves and production. This tax incentive could actually add revenues to the state treasury if focused on EOR at oil prices of \$28/B and lower under implemented technology. With advanced technology EOR, state revenues could decrease due to the analyzed tax incentive, but in-state economic activity could increase substantially at these oil prices. The state of Wyoming may wish to forego some tax revenues for gains in other areas of the state economy.

The results indicate a significant potential synergy between a tax incentive and advances in technology. The combined effects of the analyzed incentive and attainable improvements in the recovery techniques considered could result in significant incremental reserves and a cost-effective method for

Table VI-3

**Summary of Federal Economic Benefits and Trade-offs of
Analyzed Tax Incentive on EOR in Wyoming***

Oil Price (\$/B)	Tax Structure	Implemented Technology		Advanced Technology	
		Direct Federal Revenues (\$ Millions)	Imports Avoided (\$ Millions)	Direct Federal Revenues (\$ Millions)	Imports Avoided (\$ Millions)
\$16	Base	0	0	0	0
	Incentive	0	0	0	0
\$20	Base	0	0	30	2,273
	Incentive	3	776	44	3,701
\$24	Base	-1	204	84	4,864
	Incentive	45	1,201	141	6,869
\$28	Base	67	1,466	266	8,655
	Incentive	108	2,328	352	10,262
\$32	Base	179	2,254	761	10,651
	Incentive	241	2,665	947	12,162
\$36	Base	269	2,606	1,197	12,787
	Incentive	378	3,332	1,429	14,434

* The economic effects of a tax incentive on EOR only are shown here; because ASR is less sensitive to the price of oil than EOR is, the economic effects of a tax incentive on ASR are marginal.

stimulating economic activity in Wyoming (Table VI-4). At an oil price of \$24/B, advances in EOR technology combined with a focused state tax incentive could lead to additional incremental reserves of over 310 million barrels and an additional \$4.6 billion in state economic activity at a cost of \$34 million in foregone state tax revenues. A well-formulated policy of RD&D combined with economic incentives for the field application of resulting technologies provides the best opportunity for maximizing recovery from known Wyoming fields.

The national treasury and economy could also benefit substantially from such a program in Wyoming. The results indicate that the sharing of costs and benefits between the state and Federal levels

Table VI-4

**The Combined Impact of a State Tax Incentive and Technology
Advances on Potential Reserves and State Economic Activity
from EOR Activities**

Oil Price (\$/B)	Incremental Reserves (Million Barrels)			State Economic Activity (\$ Millions)		
	Implemented Base	Advanced Incentive	Difference*	Implemented Base	Advanced Incentive	Difference*
\$16	0	0	0	0	0	0
\$20	0	194	194	0	2,497	2,497
\$24	8	322	314	136	4,765	4,629
\$28	52	420	368	869	7,001	6,132
\$32	83	434	351	1,419	7,958	6,539
\$36	85	455	370	1,588	9,153	7,565

* Reflects the combined impact of technology advances and the proposed tax incentive.

could maximize reserves and production to the benefit of operators and the entire public sector. A state tax incentive in Wyoming should therefore remain a viable option to stimulate operator response to new technologies which require wide-scale field testing and application. Coordinated, focused economic policies and continued private and public RD&D to improve oil recovery techniques can help to maximize the recovery potential of the critically important Wyoming oil resource. The benefits could be realized in the form of increased oil production, a stronger domestic oil industry, lower foreign oil imports, larger public sector revenues, and increased state and Federal economic activity.

As previously discussed, the impact of the FY91 Federal EOR tax credit somewhat reduces the effect of a state tax incentive. The inclusion of the EOR tax credit in the analytical system used in this study leads to a conservative estimate of impact of the state tax incentive. To the extent that the amount of the EOR tax credit is limited by the alternative minimum tax (AMT), the potential impact of the EOR tax credit may be overstated. Therefore, the impact of the state tax incentive presented here could be understated.

The state incentive analyzed here could stimulate substantial incremental reserves; thus, much of the oil that would otherwise be left in the reservoir and abandoned after conventional production ends can be recovered economically by operators with this tax incentive. As discussed in Chapter V, advances in technology can also stimulate relatively large additions to Wyoming reserves and production. The application of a focused tax incentive and attainable improvements in recovery technologies could result in even greater increases in reserves and production potential. The results of this analysis indicate that a coordinated RD&D and tax incentive policy to encourage operators to increase recovery from known Wyoming fields could bring significant benefits to the state of Wyoming and the nation as a whole.