An Evaluation of Known Remaining Oil Resources in the State of Illinois

Project on Advanced Oil Recovery and the States

Prepared by

Interstate Oil and Gas Compact Commission

November 1993

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An Evaluation of Known Remaining Oil Resources in the State of Illinois

Volume III

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**Project on Advanced Oil Recovery and the States
Interstate Oil and Gas Compact Commission**

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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 Illinois. 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, three-fifths of the known original-oil-in-place will remain in Illinois oil reservoirs.
- The remaining resource, over 5.6 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 required to reacquire the leases, rebuild the infrastructure, and more importantly, drill new wells to regain access to the Illinois target resource.
- Illinois' 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 Illinois production and reserves and the accelerating level of well abandonment over the past decade.
- The effective transfer of existing technology could result in 60 to 70 million barrels of new reserves from analyzed Illinois reservoirs at oil prices ranging from \$20/B to \$28/B, potentially increasing the state's current proved reserves by 50%.
- Technology advances resulting from a focused RD&D effort could result in *additional* post-conventional reserves of 15 to 70 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 Illinois.
- Public sector revenues from future improved oil recovery activity would total between \$160 and \$320 million, given currently available recovery practices and oil prices of \$20/B to \$28/B. Technology advances could increase these totals by \$40 to \$190 million over the same price range, with roughly 50% of the total flowing to the state treasury.
- Potential improved oil recovery would replace imports of foreign oil, keeping between \$1 billion and \$2 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 54 major Illinois 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 Illinois' 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, Illinois 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 Illinois and the nation as a whole.

I. OVERVIEW

A. THE PROBLEM: DECLINING ILLINOIS OIL PRODUCTION

Over three-fifths of the oil discovered in the state of Illinois will remain trapped in the reservoir at the conclusion of conventional oil recovery operations. The total known original oil-in-place in Illinois has been estimated at nearly 9.2 billion barrels (Figure I-1). Almost 3.4 billion barrels had already been produced at the end of 1991. Nearly 130 million barrels of proved reserves are still producible under existing economic conditions, using currently available technologies. The remaining 5.6 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

Known Illinois Oil Resource

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

- Declining state production and reserves. Illinois oil production has declined by 75% from 1962 through 1991 (Figure I-2A). Crude oil reserves decreased by roughly the same percentage over the same time period (Figure I-2B). Although this decline has leveled off over the past 20 years, 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 Illinois currently produces oil from roughly 33,000 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 Illinois 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 Illinois oil production. The development of new exploration techniques and secondary recovery technology has acted to reverse past production declines and has allowed Illinois to maintain and increase its producible oil and gas resources. Oil producers in the state of Illinois have also pioneered significant developments in enhanced oil recovery technology, particularly in the case of chemical flooding and improved waterflooding techniques. 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 Illinois petroleum community, to arrest the decline in production and maximize recovery of the state's oil resource.

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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

Illinois Production and Reserves

A) Annual Production

B) Reserves

B. THE OPPORTUNITY: OIL RECOVERY THROUGH ADVANCED TECHNOLOGY

The remaining oil resource constitutes a large target for future recovery operations. The 5.6 billion barrels of known unrecovered oil in the state of Illinois 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 trapped in the reservoir pores by viscous and capillary forces and cannot be displaced by water.

The estimated unrecovered mobile oil (UMO) resource in Illinois is 1.3 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 4.3 billion barrels of remaining immobile oil in Illinois 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

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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 by modeling ASR processes. In this report, the future potential of EOR and ASR techniques are examined with the following key assumptions and considerations:

- A total of 54 Illinois reservoirs, accounting for 5.6 billion barrels (60%) of the known original oil-in-place in the state, were individually analyzed for their EOR and ASR potential (Figure I-3). No attempt is made to extrapolate the results to the remaining Illinois 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 Illinois and Federal tax structures. The FY 1991 Federal EOR tax credit is included in this analysis.
- The recovery potential evaluated in this report is for future new projects only and does not include incremental reserves from existing EOR projects. However, the expansions to the existing projects, if technically and economically feasible, are evaluated as part of future new projects.

C. BENEFITS DERIVED FROM IMPROVED OIL RECOVERY

Potential incremental reserves 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 12 and 71 million barrels of incremental reserves across the entire oil price range. Advanced technology applied to the same resource base could stimulate an additional 49 to 72 million barrels of incremental resources for a total of 61 to 143 million barrels beyond currently proven reserves. In effect, improvements in process performance and application could more than double the reserves possible under implemented technology conditions. This clearly provides a major justification for a focused RD&D and technology transfer program.

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

Figure I-3

Illinois 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, only about 11 million barrels across the entire oil price range. Advances in EOR technology could stimulate an additional 60 million barrels of incremental reserves at higher oil prices. This means that over 70 million barrels of potential incremental reserves from EOR exists under the two levels of technology for the analyzed reservoirs.

Reserve additions attributed to ASR techniques are impacted much less by oil price changes than EOR. About 60 million barrels of ASR reserves could be added in the implemented technology case at oil prices of \$20/B to \$36/B. Research on process improvements, specifically improved polymer flooding and profile modification combined with geologically targeted infill drilling, could increase ASR potential by 20%. With advances in technology, incremental ASR reserves could total about 12 to 14 million barrels more than implemented technology over the price range analyzed, for a total of 70 million barrels of potential ASR reserves.

Future improved oil recovery activities will generate revenues for Illinois and the Federal treasury through increased state corporate and personal income 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 Illinois could directly generate \$48 million in state revenues. At the same oil price, advanced technology could generate an additional \$18 million, for a total of \$66 million in state revenues (Figure I-4). At an oil price of \$28/B, application of currently available EOR and ASR technology could contribute \$87 million to the Illinois public treasury while the application of advanced methods could increase these revenues by an additional \$119 million to a total of \$206 million.

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 wellhead oil price, is a simple measure of Illinois' contribution to reducing the trade deficit. As shown in Table I-1, this figure could total between \$1.1 billion and \$2.0 billion under the implemented technology scenario, over the \$20/B to \$28/B range. Advanced technology could further decrease imports by an *additional* \$0.3 billion to \$2.0 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 Illinois**

Oil Price and Technology Level	Potential Reserves (Million Barrels)	Incremental State and Local Revenues (\$ Millions)	Incremental Imports Avoided** (\$ Millions)	Increased Federal Revenues (\$ Millions)
<u>At \$16/B</u>				
Implemented Technology	12	10	193	24
<u>Advanced Technology*</u>	<u>49</u>	<u>35</u>	<u>781</u>	<u>38</u>
Total	61	45	974	62
<u>At \$20/B</u>				
Implemented Technology	56	48	1,108	111
<u>Advanced Technology*</u>	<u>14</u>	<u>18</u>	<u>287</u>	<u>21</u>
Total	70	66	1,395	132
<u>At \$24/B</u>				
Implemented Technology	69	70	1,638	167
<u>Advanced Technology*</u>	<u>29</u>	<u>37</u>	<u>723</u>	<u>30</u>
Total	98	107	2,361	197
<u>At \$28/B</u>				
Implemented Technology	71	87	1,978	234
<u>Advanced Technology*</u>	<u>71</u>	<u>119</u>	<u>1,979</u>	<u>67</u>
Total	142	206	3,957	301
<u>At \$32/B</u>				
Implemented Technology	71	99	2,266	311
<u>Advanced Technology*</u>	<u>65</u>	<u>118</u>	<u>2,085</u>	<u>195</u>
Total	136	217	4,351	506
<u>At \$36/B</u>				
Implemented Technology	71	113	2,598	382
<u>Advanced Technology*</u>	<u>72</u>	<u>145</u>	<u>2,539</u>	<u>306</u>
Total	143	258	5,137	688

*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 12 million to nearly 70 million barrels from the state of Illinois' largest, most mature reservoirs at oil prices of \$16/B to \$24/B. With the technology advances resulting from focused RD&D, an additional 30 million barrels to nearly 50 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 2.6 billion barrels of immobile oil would still remain in the analyzed reservoirs as a long-term target for future advances in EOR, and 0.7 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 is not indefinite. 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 Illinois 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 Illinois, 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-5

Illinois Remaining Oil Resource After Advanced Technology Recovery

II. BACKGROUND AND OBJECTIVES

A. TRENDS IN ILLINOIS OIL PRODUCTION AND RESERVES

As would be expected of a state in the mature stage of its production history, since the early 1960s oil production in Illinois has consistently declined except for a period of growth in the first half of the 1980s (Figure II-1). Between 1955 and 1962, Illinois production remained consistently high at approximately 80 million barrels per year. Over the seventeen years from 1962 to 1979, Illinois production dropped by an average of 4% per year, reaching a low of fewer than 22 million barrels in 1979. The 75% fall in Illinois oil production over the last thirty years can be attributed to price changes and the decreasing yield from conventional recovery as the fields in the state have matured. Crude oil price increases in the mid to late 1970s exposed oil production in Illinois to the influences of the world energy market. The doubling of world oil prices from 1979 to 1981 accounted for the short term reversal of the decline in Illinois oil production. However, with the oil price collapse of 1986, annual production declined again, hitting an all-time low of fewer than 20 million barrels in 1991.

The decrease in Illinois oil production has been accompanied by a general reduction in reserves (Figure II-2). State crude oil reserves peaked in 1956 at 700 million barrels. By 1980, reserves had fallen by almost 84% to just 113 million barrels. Increased oil prices did restore some activity by Illinois operators during the first half of the 1980s, increasing reserves to approximately 150 million barrels. The general trend in Illinois suggests that even a restoration of moderately high oil prices would not significantly extend the conventional recovery life of mature Illinois fields.

The general declines in production and reserves cannot be attributed to a drop in the number of producing wells, as this number has increased steadily over the last fifteen years. In 1975, Illinois had just over 23,000 producing wells before major increases in field development saw that number rise to 31,000 in 1985 (Figure II-3). In the past six years, lower oil prices have caused a leveling off in the number of producing wells as stripper wells have been abandoned and development has declined. As of 1991, there were over 32,000 producing wells in Illinois. Reserves per producing well have plummeted as the number of wells have increased. Through 1970, reserves per well averaged more than 8,000 barrels; that number has since dropped to approximately 4,000 barrels per well in 1991.

Figure II-1

Illinois Crude Oil Production (1950 - 1991)

Figure II-2

Illinois Crude Oil Reserves (1950 - 1991)

Compounding the problem of recent production slides has been the increasing reliance on stripper wells, which produce fewer than 10 barrels of oil per day on average. As of 1990, stripper wells accounted for more than 92% of Illinois production (Figure II-4). These marginal wells maintain economic access to the reservoirs they penetrate and are critical to future applications of new, modern recovery techniques. Future economic events that threaten the viability of continued production, such as another oil price collapse, would dramatically reduce access to a large portion of the Illinois resource, making improved oil recovery economically impossible. Between 1980 and 1990, over 4,400 Illinois stripper wells have been abandoned, limiting access to the oil resource remaining in older producing zones.

Clearly, this trend of declining production has implications for employment and economic activity in Illinois. In 1979, the Illinois oil and gas industry employed nearly 77,000 people, with only 5,300 in the extraction sector (Figure II-5). Since then, however, oil and gas employment in Illinois has been steadily declining. In 1991, fewer than 59,000 people in the state were employed in the oil and gas industries, and the number of people employed in the extraction sector has fallen by about 50% since the mid-1980s. With production and reserves trends likely to continue on their present course, these employment figures may drop even further in the near future.

Over this same period, the gross annual value of Illinois oil production has experienced dramatic changes (Figure II-6). The value of production, in constant 1991 dollars, increased rapidly in the late 1970s and early 1980s along with the price of oil, reaching an all-time high of over \$1 billion in 1980. With the oil price collapse of the mid-1980s, however, the value of oil production dropped over 65% to a low of around \$365 million in 1988. Recent increases in the value of oil production reflect a mild recovery in oil price which may help to spur future development efforts.

The loss of tax revenue, caused by declining production in the oil and gas industries, has not had a significant impact on total state tax revenues, because Illinois does not levy severance taxes on oil and gas production. Thus, it is unlikely that future declines in production will severely impact the Illinois tax base. However, because of the effect on employment levels and income tax revenues, oil and gas production have played an important role in the state's economy. It is in the state's, and the nation's, best interest to maximize the future recovery of Illinois' remaining resource.

Figure II-3

Figure II-4

Figure II-5

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

Figure II-6

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

Figure II-7

Illinois Oil Resource

At the conclusion of conventional primary and secondary operations, vast quantities of oil will remain unrecovered in Illinois reservoirs (Figure II-7). The total known original oil-in-place (OOIP) in Illinois is estimated at 9.2 billion barrels. Approximately 3.4 billion barrels are estimated to be recovered through the use of conventional oil recovery techniques (37%). Over 5.6 billion barrels, 61% of the oil resource, will remain in Illinois reservoirs after conventional recovery techniques have been applied and wells reach their economic limit. This remaining oil is the target for newer, more efficient extraction techniques.

This unrecovered resource can be broken down into two main components: mobile and immobile oil. In Illinois, 1.3 billion barrels of unrecovered mobile oil (UMO) make up the target of a number of

advanced primary and secondary recovery processes, collectively referred to as advanced secondary recovery (ASR). The 4.3 billion barrels of remaining immobile oil represents the target for a number of tertiary extraction technologies, defined generally as enhanced oil recovery (EOR). Recovery operations directed at each of these resources could play a critical role in sustaining the Illinois oil industry. A brief overview of these recovery technologies 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 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, either natural influx or water injection.

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 polymer-augmented waterflooding), and other reservoir management techniques is to contact the oil in the unswept zones, prior to or along with EOR applications.

1. Enhanced Oil Recovery

Proven enhanced recovery processes are classified into three categories: gas-miscible, chemical, and thermal. Very few gas-miscible or thermal projects have been implemented in known Illinois reservoirs at this time. Chemical flooding is the most prevalent EOR technique used in the state of Illinois. As early as 1980, Marathon Oil Company had established three chemical EOR projects in the S formation of Crawford county's Main Consolidated field. Two of these were established as micellar polymer floods, a unique type of surfactant flood in which polymer slugs are added to the chemical slug.

The third project was established as a straight polymer flood, and will be discussed in Section C. They were producing a total of about 100 barrels of oil per day (BOPD) when Marathon sold the projects to Crete Oil.¹ These projects were not determined to be profitable for Marathon, but the technical recovery potential of chemical flooding has been clearly established. Marathon also initiated two surfactant flooding projects in the S formation of Lawrence county's Lawrence-Robinson field. These two projects were established in 1982 and 1985 and produce a combined total of approximately 70 incremental barrels per year. These projects, while not yet profitable, appear promising.² At least a dozen small (usually 10 acres) surfactant microemulsion projects were reportedly initiated between 1977 and 1980.³ The literature makes no further mention of them.

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, to the higher viscosity of oil than injected water, and to permeability variations within the reservoir. The effectiveness

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¹ *Oil and Gas Journal*, Moritis, Guntis, 20 April 1992.

² *Ibid.*

³ U.S. Department of Energy, Bartlesville Project Office, Enhanced Oil Recovery Project Data Base, April 1992.

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 also 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, as demonstrated by the prevalence of ASR techniques in larger oil producing states such as Texas. Several distinct methods for producing unrecovered mobile oil 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.

Fifty infill wells have been drilled by Exxon in the Loudon field of Illinois since 1979. Prior to the infill drilling, production from the Loudon field averaged approximately 25 barrels of oil per day. Now, these wells produce an estimated total of 600 barrels of oil per day (BOPD), or 18% of Exxon's total field production. Because of the maturity of the Loudon field, essentially all production from these wells is considered increased recovery due to the infill drilling program. These infills are expected to increase the Loudon field oil reserves by 970,000 barrels⁴.

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⁴ Barber, A.H., Jr. et al., "Infill Drilling to Increase Reserves -- Actual Experience in Nine Fields in Texas, Oklahoma, and Illinois," *Society of Petroleum Engineers (SPE) Paper #11023*, 1982.

The potential benefits of geologically targeted infill drilling have been assessed by several research studies.^{5,6,7} One study, mounted by the Illinois State Geological Survey, is evaluating reservoir development strategies for some of the state's older producing oil fields.⁸ This study is currently focusing on infill drilling techniques and injection patterns in two of Illinois' most prolific producing formations -- the Mississippian Cypress and Aux Vases sandstones. These studies indicate substantial recovery potential from targeted infill drilling.

Two polymer flooding projects have been reported in Illinois. The first was established by Marathon in Crawford county's Main Consolidated field. This project was discontinued and the property sold. The second project, established by South Fork, Inc. in the S formation of Clark county's S. Johnson field, while considered profitable, has been postponed pending further analysis. Of the 36 BOPD produced by the 50 acre, 60 well project, 20 BOPD was considered to have been the result of enhanced recovery.⁹ Currently, there are no profile modification processes being implemented in Illinois reservoirs.

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.

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⁵ 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.

⁶ Fisher, W.L., "Can the U.S. Oil and Gas Resource Base Support Sustained Production?" *Science*, Volume 236, No. 4809, 26 June 1987, 1631-1636.

⁷ Tyler, et al., *Oil Accumulations, Production Characteristics, and Target for Additional Recovery in Major Oil Reservoirs in Texas*, the Bureau of Economic Geology, The University of Texas at Austin, Geological Circular 84-2, 1984.

⁸ *Improved Recovery Week*, Pasha Publications, Arlington, VA, 27 July 1992.

⁹ *Oil and Gas Journal*, Moritis, Guntis, 20 April 1992.

There are several other processes and recovery techniques which were not included in this analysis which may have potential in Illinois. 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.

Fifty-four reservoirs, accounting for 5.6 billion barrels of origin oil-in-place (over 60% of the total known resource in Illinois), were included in this analysis. These reservoirs contain 3.4 billion barrels of remaining oil resource (Figure II-8). The 800 million barrels of UMO is the target for application of ASR processes and 2.7 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 R&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-8

Illinois 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

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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

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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	- 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	- 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 54 of the largest Illinois reservoirs, accounting for over 60% of estimated original oil-in-place (OOIP) in the Illinois. 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 Illinois. 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 Illinois.

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 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

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

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 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

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

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 Illinois 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 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 Illinois 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 Illinois 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 Illinois. 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 Illinois, 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 Illinois (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 Illinois 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 Illinois 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 Illinois oil resource. Direct Federal taxes total 5% to 20% of the value of each barrel of oil recovered. Each additional barrel of Illinois 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 Illinois on the Federal treasury.

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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 ILLINOIS 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 Illinois 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 ($\text{API} > 20$ degree) and heavy oil ($\text{API} \leq 20$ 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 54 reservoirs in Illinois for their EOR and ASR potential. The results of this analysis were not extrapolated to the rest of the reservoirs making up the Illinois resource.

B. RECOVERY OF THE REMAINING IMMOBILE OIL RESOURCE

1. Production and Reserves

Over the price range analyzed, EOR processes (carbon dioxide-miscible, chemical, and thermal) could stimulate only 11 million barrels of incremental reserves under implemented technology. This

potential represents a single CO₂-miscible flooding project which could be economic at oil prices of \$24/B and above.

2. Increases in State and Local Revenues

This 11 million barrels of EOR production could increase direct state and local revenues through state corporate and personal income taxes and sales taxes on purchased materials used in the projects. (The state of Illinois does not levy a production tax on oil or gas.) The estimated revenues are generated directly from oil production or operations in the analyzed Illinois reservoirs. State and local revenues generated over the life of the single EOR project vary with oil prices (Figure IV-1). The most significant portion of these revenues could result from sales taxes. A \$24/B oil price could yield sales tax revenues of \$6 million plus \$4 million in other tax receipts. At \$36/B, corporate income and sales tax receipts each could contribute \$8 million with personal income taxes comprising the remainder of the \$18 million total.

3. Effects on the State Economy

In addition to the incremental state and local revenues, enhanced oil recovery would benefit Illinois by increasing economic activity and by creating new jobs. The effects of EOR on the state economy are estimated conservatively: (1) only direct effects are included (i.e., no economic multiplier); and (2) the direct effects are limited to benefits believed to accrue predominantly to the state of Illinois 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 activity. However, to the extent that royalties go to the Federal government, the royalties portion of state economic activity could be overstated. While the excluded elements undoubtedly aid Illinois' citizens to some degree, a substantial portion of the benefits will be enjoyed by citizens of other states. As local manufacture or retail sales of these items provide economic benefits within Illinois, injectants produced or manufactured in Illinois are employed, or economic "multipliers" occur, the calculated economic impacts are understated.

Figure IV-2 displays the total direct economic gains for the state over the applicable oil price range analyzed. Operating costs could account for about 70% of these economic effects; royalties could represent around 20%; intangible investment could be about 5%, and state revenues could be about 5%

Figure IV-1

Direct State and Local Revenues from EOR Production Implemented Technology

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

to 7% of the total. At \$24/B, incremental benefits to the state economy could exceed \$190 million. At the highest oil price considered, \$36/B, an estimated \$262 million of statewide direct economic activity could be stimulated by this single EOR project. Successful EOR projects can create or maintain jobs in the local economy, as shown in Figure IV-3. The number of jobs created or maintained by this EOR project during peak years could nearly reach 120 per year. Total incremental annual wages paid could reach over \$5 million.

4. Effects on the National Economy and Budget

Increased oil recovery from EOR in Illinois would benefit the nation as a whole. National benefits would accrue in several ways: replacement of oil imports, increased Federal corporate and personal income tax revenues, and reduction in the foreign trade deficit. Of course, the addition of only 11 million barrels of reserves in Illinois would not appreciably expand the nation's proved reserve base. However, as each additional barrel of domestic oil production replaces a barrel of imported oil, the nation's energy security would be enhanced.

Figure IV-2

Direct State Economic Activity*

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-3

Jobs and Wages from EOR Production

Implemented Technology

EOR activity in Illinois contributes to the Federal treasury through personal and corporate income taxes. Increases in Federal revenues stimulated by implemented technology EOR could range from \$3 million at \$24/B to \$43 million at \$36/B, over the life of the projects (not illustrated). Corporate income taxes could account for between 50% and 80% of this total at oil prices of \$28/B and above, and personal income taxes would make up the remainder. Negative Federal revenues result from taxable losses generated during the initial implementation phases of many EOR projects, as well as from the Federal EOR tax credit, both of which are assumed to be used as offsets to Federal income tax liabilities from other profitable activities. Federal corporate income taxes were evaluated at a marginal tax rate of 34%.

In addition to directly replacing imported oil, increased domestic production would reduce the foreign trade deficit. The money spent purchasing domestic rather than imported oil circulates back through the U.S. economy instead of adding to the trade deficit. Implemented technology EOR in Illinois could stimulate from \$261 million (at \$24/B) to \$410 million (at \$36/B) of imports avoided, over the life of the project.

C. RECOVERY OF THE REMAINING MOBILE OIL RESOURCE

This section will discuss the application of currently available advanced secondary recovery (ASR) processes in analyzed Illinois reservoirs. These two distinct recovery technologies, enhanced oil recovery and advanced secondary recovery, have been addressed separately to illustrate the potential benefits of each. However, since the resource target of these two technologies is different, both could be simultaneously implemented, making the results at least additive. Given the potential synergies in the simultaneous employment of EOR and ASR technologies, reserve additions and economic benefits could be even greater than the sum of the two.

1. Production and Reserves

ASR processes applied in the reservoirs analyzed could stimulate 12 to 60 million barrels of incremental reserves over the analyzed oil price range. ASR processes are less costly to implement than EOR processes, and therefore ASR reserve additions are less sensitive to changes in the oil price. At \$20/B, ASR could generate 56 million barrels of incremental reserves, more than 90% of the oil economically accessible at oil prices above \$28/B.

This analysis evaluates five ASR processes: polymer flooding, profile modification, infill drilling, and combinations of infill drilling with polymer flooding or profile modification. Polymer flooding and profile modification projects are grouped together in the following discussion, as are infill drilling combinations with polymer flooding and profile modification. As shown in Figure IV-4A and Table IV-1A, infill drilling, both by itself or in combination with the other processes, could account for all of the reserve additions at all prices. At \$16/B, the combination processes could be the only economic processes and could stimulate 12 million barrels of incremental reserves. As oil prices increase, infill drilling alone becomes more economic since revenues increase along with oil prices. Between \$20/B and \$36/B, there would be little change in the total incremental reserves or in their distribution between infill drilling and combination processes. Table IV-1B shows the number of projects expected to be economic at each price for individual recovery methods. At all prices above \$16/B, the number of advanced secondary recovery projects in each category could remain relatively constant.

Figure IV-4B displays the expected annual production from ASR processes for oil prices of \$16/B and \$32/B. Timing of the ASR potential has been carried out according to the methodology discussed in Chapter III. The peak at \$16/B is about 360,000 barrels of oil per year from two projects. At \$32/B, production from ASR could peak at is about 2 million barrels annually from eight projects. To put the potential contribution of ASR into perspective, 2 million barrels per year is equivalent to about 10% of current Illinois annual oil production.

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. Some fields could therefore be abandoned before ASR can be implemented. This abandonment, which is reflected in the annual production, is on the order of 25% to 35% of the potential incremental reserves. Accelerated technology transfer can reduce this loss.

2. Increases in State and Local Revenues

Figure IV-5 shows the expected growth in state revenues from ASR production and the proportional contributions of state corporate and personal income taxes and sales taxes to the total. Corporate income taxes could account for 40% to 70%, with sales taxes making up most of the remaining revenues. At moderate oil prices (\$20/B to \$28/B), between \$48 million and \$73 million in additional direct state and local revenues could be generated from activities associated with ASR production. At \$36/B, \$95 million in direct state and local revenues could be stimulated.

Table IV-1A

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

Oil Price (\$/B)	Infill Drilling	Infill Drilling and Polymer Flooding or Profile Modification	Total
\$16	0	12	12
\$20	43	13	56
\$24	45	13	58
\$28	47	13	60
\$32	47	13	60
\$36	47	13	60

* Polymer flooding and profile modification, applied alone, did not exhibit potential using implemented technology.

Table IV-1B

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

Oil Price (\$/B)	Infill Drilling	Infill Drilling and Polymer Flooding or Profile Modification	Total
\$16	0	2	2
\$20	3	3	6
\$24	4	3	7
\$28	5	3	8
\$32	5	3	8
\$36	5	3	8

* Polymer flooding and profile modification, applied alone, did not exhibit potential using implemented technology.

Figure IV-4

Reserves and Production Response from ASR Techniques

Implemented Technology

A) Incremental Reserves by ASR Process

B) Annual Production from ASR Reserves

Figure IV-5

Direct State and Local Revenues from ASR Production Implemented Technology

3. Effects on the State Economy

Figure IV-6 displays the total state economic activity associated with potential ASR production. Total state economic activity from the processes could range from about \$100 million at \$16/B to about \$1.2 billion at \$36/B. Intangible investments would be the largest component of these increases in state economic activity and could amount to about 50% of the total. These costs could range from nearly \$420 million to over \$540 million at oil prices between \$20/B and \$36/B. Operating costs and royalties would be the next largest components of increased economic activity, each averaging approximately 20% of the total activity across all oil prices. State taxes would contribute the remaining 5% to 10%.

The implementation of ASR techniques could significantly contribute to employment in the state of Illinois. Figure IV-7 displays the annual number of jobs that could be created or maintained by ASR projects. The annual trend in jobs created or maintained closely matches the production trend for ASR.

Figure IV-6

Direct State Economic Activity

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-7

Jobs and Wages from ASR Production

Implemented Technology

At \$32/B, the number of jobs created or maintained could peak in year 2016 at a level of about 100. At this price, \$4.7 million in wages could be paid in the peak employment year.

4. Effects on the National Economy and Budget

Tax revenues from activities associated with ASR production could significantly add to the Federal treasury (Figure IV-8A). At moderate oil prices (\$20/B to \$28/B), between \$111 million and \$220 million in additional direct Federal revenues could be stimulated by ASR production, mostly from corporate income taxes. At \$36/B, nearly \$340 million in direct Federal revenues could be added to the national treasury.

Sixty million barrels of increased domestic ASR production through implemented technology would also enhance the nation's energy security and reduce reliance on imported oil. To the extent that one barrel of domestic production replaces one barrel of imports, the foreign trade deficit is reduced as dollars which would be paid for foreign oil are spent domestically (Figure IV-8B). Between \$1.1 billion and \$1.7 billion could be spent on domestic oil rather than imports at oil prices ranging from \$20/B to \$28/B. At \$36/B, the value of imports avoided could reach over \$2.1 billion.

D. CONCLUSIONS

The existing level of EOR and ASR technologies could make small, but important, contributions to the reserve base and the Illinois and national economies, as well as to domestic energy security. At a \$24/B oil price, EOR processes could add 11 million barrels to Illinois reserves while ASR techniques could add 58 million barrels of incremental reserves. The application of current EOR and ASR technologies, in concert, could potentially add nearly 70 million barrels of incremental reserves at this price, adding over half Illinois'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 Illinois and its citizens stand to gain significantly from the increased production resulting from incremental reserve additions. Production increases could generate \$50 million to \$100 million in additional state and local revenues over the life of the analyzed projects assuming oil prices of \$20/B to \$32/B. Total state economic activity would be boosted by \$780 million to \$1.3 billion. Jobs

Figure IV-8

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.

would be created or maintained, and state economic activity would increase. The national economy would 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 Illinois should therefore be an important goal for state and Federal policy makers. While these benefits would be available using currently available technology, the true potential would 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-9, 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 improved recovery technologies. Of the 2.7 billion barrels of immobile oil resource analyzed in this study, implemented technology EOR practices as defined in this report could produce an estimated 11 million barrels of incremental reserves at an oil price of \$36/B, leaving over 2.6 billion barrels of remaining immobile oil in these reservoirs. Of the 750 million barrels of unrecovered mobile oil in the reservoirs analyzed, implemented technology practices could produce an estimated 60 million barrels of incremental reserves at \$36/B, leaving 690 million 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-9

Illinois Remaining Oil Resource After Implemented Technology Recovery

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

A. INTRODUCTION

While currently available enhanced oil recovery (EOR) and advanced secondary recovery (ASR) techniques could contribute substantially to the Illinois reserve base, technological advances in these processes resulting from a focused RD&D effort would have far more dramatic effects on the state's oil production. Development and wide-scale application of improved recovery 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 reserves potential in the state of Illinois are presented separately. Given that the modeled advances in technology are conservatively defined, improvements in recovery processes resulting from RD&D not envisioned in this report could add substantially to the estimated 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 Illinois 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, substantial reductions in the associated risk of EOR projects are modeled as a reduction in the minimum rate of return, or hurdle rate, required for project implementation.

2. Production and Reserves

With technology advances, EOR could stimulate a substantial amount of incremental reserves over the applicable oil price range (\$24/B to \$36/B) analyzed in this study (EOR was not found to be economic at prices below \$24/B). Figure V-1 and Table V-1A show the comparison between the incremental reserves potentially generated through the application of advanced technology EOR processes and implemented technology EOR processes. At \$24/B, the incremental reserves due to advances in technology could be greater than those generated in the implemented technology case. At \$28/B, advances in EOR technology could add 60 million barrels of incremental reserves to implemented technology potential for a total of over 70 million barrels of incremental reserves (more than six times implemented technology reserves).

The potential incremental reserves contributed by each of the advanced EOR processes considered in this analysis are also shown in Figure V-1. Over the \$28/B to \$36/B range, advanced chemical flooding and advanced CO₂-miscible flooding processes could contribute approximately 60% and 40%, respectively to the total potential. Advanced technology chemical flooding potential would not be economic in the analyzed Illinois reservoirs below a \$28/B oil price under advanced technology conditions, and would not be economic under implemented technology conditions at any price evaluated in this study.

Figure V-1

Incremental Reserves by EOR Process Implemented Technology vs. Advanced Technology

At \$24/B and above, advanced CO₂-miscible flooding could increase implemented technology incremental reserves by over 150% for a total potential of about 28 million barrels. Advanced chemical processes could stimulate over 40 million barrels to the total incremental reserves at oil prices of \$28/B and greater, all of which could be incremental recovery due to technology advances attainable through RD&D. Advanced thermal processes were not found economic at any of the oil prices considered in this analysis under either of the technology scenarios.

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. The number of economic CO₂-miscible projects does not change, but reserve potential increases, indicating that advanced technology CO₂-miscible flooding is more efficient than the implemented technology process in the reservoirs analyzed, but that the project economics were not significantly improved. The chemical projects could first become economic in the advanced case at oil prices of \$28/B and greater; this process was not economic under implemented technology. This increase indicates that improved project economics are attainable from advanced technology; the additional reserves due to advanced technology would come from reservoirs that were not economic to develop under implemented technology.

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+
\$24	11	28	0	0	11	28
\$28	11	28	0	43	11	71
\$32***	11	28	0	37	11	65
\$36	11	28	0	43	11	71

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

* Analyzed Illinois reservoirs did not exhibit thermal EOR potential.

** The analysis reported no economic projects at prices below \$24/B.

*** Decrease at \$32/B caused by the phaseout of the Federal EOR tax credit.

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
\$24	1	1	0	0	1	1
\$28	1	1	0	6	1	7
\$32***	1	1	0	5	1	6
\$36	1	1	0	6	1	7

* Analyzed Illinois reservoirs did not exhibit thermal EOR potential.

** The analysis reported no economic projects at prices below \$24/B.

*** Decrease at \$32/B caused by the phaseout of the Federal EOR tax credit.

Figure V-2 shows the expected annual EOR production at oil prices of \$24/B and \$32/B for both the implemented and advanced technology cases. At \$24/B, over 1.6 million barrels per year could be added to Illinois oil production within 10 years as a direct result of advances in EOR technology. At \$32/B, the same production trends could be seen; production from advanced technology chemical floods would not occur until after the year 2020. The total peak annual production of 2.7 million barrels could increase 1991 Illinois production levels by 14%.

3. Effects on State Revenues and Economic Activity

At all applicable oil prices considered in this analysis, the direct revenues to the state of Illinois attributable to EOR could significantly increase due to advanced technology (Figure V-3A). Similar to the implemented technology case, state corporate income and sales taxes could make up most of the state's total direct revenues, and personal income tax receipts could contribute the remainder (Illinois does not levy a production tax on oil or gas). At \$24/B, total direct state revenues stimulated by advanced technology EOR could amount to \$27 million, \$16 million greater than implemented technology. At oil prices of \$28/B to \$32/B, advances in EOR technology could generate up to \$95 million in incremental revenues (over six times implemented technology potential). The \$110 million in direct state tax revenues at these prices would be a significant addition to the state treasury.

Direct state economic activity generated by Illinois EOR could also grow due to advanced technology. Figure V-3B displays the potential incremental direct economic benefits to the state for both the implemented and advanced technology cases. The advanced technology distribution of total economic benefits among the contributing components would be similar to the trend shown for the implemented technology case. At \$24/B, the incremental state economic gain attributable to advances in EOR technology could nearly double the amount in the implemented technology case, for a total potential of over \$540 million. At \$28/B, the direct state-wide economic gain could increase from less than \$225 million under implemented technology to over \$1.4 billion with advanced EOR technology development. At \$36/B, an additional \$1.6 billion in direct state economic activity could be generated by advanced technology EOR activities. At oil prices above \$24/B, advances in EOR technology could account for \$1.2 billion to \$1.4 billion of the increases in direct state economic activity. Clearly, the state of Illinois could accrue substantial benefits from the development and application of advanced EOR technology at all of the applicable oil prices considered in this analysis.

Figure V-2

Annual Production from EOR

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 \$24/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 \$24/B.

Advanced technology also has a substantial impact on the state's employment. Even at a moderate oil price of \$24/B, the development of advanced technology could create or maintain over 146 jobs more than implemented technology EOR by the year 2002 (not illustrated). At the higher oil price of \$32/B, over 157 jobs per year could be attributable to the development of advances in technology by the year 2002, for a total of over 283 jobs per year created or maintained by advanced technology EOR projects. Peak wages at \$24/B and \$32/B due to advances in EOR technology are estimated at \$6.7 and \$7.1 million, respectively, and would occur before the year 2005. Total peak wages at these prices would be \$11.6 and \$12.7 million, respectively.

4. Effects on the National Economy and Budget

As discussed in Chapter IV, increased oil recovery in the state of Illinois through EOR methods would benefit the nation in the areas of enhanced energy security, a reduced foreign trade deficit, import replacement, and expanded direct revenues to the Federal treasury. The potential benefits are significantly more pronounced with the development of advanced technology. Over 70 million barrels of crude oil could be added to proved reserves due to advanced EOR technology, 60 million barrels of which is attributable to technology advances.

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 advances in technology (Figure V-4A). At moderate oil prices below \$28/B, there would be no increase in Federal revenues. In fact, at \$24/B, there could be a decrease from implemented technology potential. This could be caused by the Federal EOR tax credit which provides an operator with a tax credit on investment costs for EOR projects. This credit can be used to offset profits from the project or other operators. At \$28/B, the increase in potential reserves could outweigh the value of the tax credit leading to an increase in direct Federal revenues. At this price, \$36 million in direct Federal revenues (75% of the \$48 million total potential) could be attributable to technology advances. At \$36/B, after the phaseout of the EOR tax credit, EOR technology advances could stimulate \$194 million in revenues over implemented technology, for a total potential of \$237 million in direct Federal revenues.

The increase in potential reserves could also lead to a decrease in imports which would reduce the trade deficit by the effective value of the increased domestic production. To the extent that one barrel of domestic production replaces one barrel of imported oil, the value of imports avoided due to technology

advances could be substantial. At \$24/B, over \$420 million of the total \$680 million in imports avoided through application of advanced technology EOR could be attributed to technology advances. At oil prices above \$24/B, EOR technology advances could stimulate \$1.7 billion to \$2.1 billion in avoided imports (Figure V-4B). The total import replacement at these prices (\$2.0 billion to \$2.6 billion) would represent a significant reduction in the foreign trade deficit.

C. RECOVERY OF THE REMAINING MOBILE OIL RESOURCE

1. "Advanced" Technology Defined

The unrecovered mobile oil (advanced secondary recovery) 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 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 advanced secondary recovery (ASR), resulting in more activity and much greater recovery under the advanced technology 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.

Figure V-4

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 \$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.

2. Production and Reserves

The development of advanced technology ASR methods through RD&D could significantly increase the state's oil reserves. Advances in ASR technology could stimulate 12 million to nearly 40 million barrels of incremental reserves in the analyzed Illinois reservoirs. At oil prices of \$20/B and greater, incremental reserves due to technology advances could be 15% to 20% of the 70 million barrels of total potential incremental reserves from ASR. ASR is less sensitive than EOR to increases in oil price, and essentially the same increase is seen over the range of prices analyzed. The only exception would be at \$16/B when incremental reserves could increase by nearly 50 million barrels over implemented technology potential to over 60 million barrels of total incremental reserves from ASR (Figure V-5).

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 ASR method, contributing 88% to 98% of the total incremental reserves. Polymer flooding and profile modification alone increases from zero in the implemented technology case to only about 8 million barrels with advances in ASR technology. Under advanced technology, many of the implemented technology infill drilling projects could be converted to the more prolific combination projects, resulting in a sharp decrease in infill drilling potential.

Table V-2B shows the estimated number of economic ASR projects for both the implemented and advanced technology scenarios. At all oil prices analyzed, the number of infill drilling projects (applied alone) could drop by three to five projects under advanced technology. The number of combination projects (infill and polymer flooding or profile modification) could triple or quadruple, and a more than proportionate increase in incremental reserves attributable to combination processes could result. This can be explained by a shift to combination projects from infill drilling alone by those infill drilling projects which were less effective. Table V-2B also shows that the number of economic polymer flooding and profile modification projects under the advanced technology case could increase from the implemented case; the increase in incremental reserves from these processes at all oil prices considered could be directly attributable to technology advances. The number of economic projects increases as a result of assumed improvements in the chemical composition of polymer solutions that allow these solutions to withstand more severe reservoir conditions (e.g., higher temperature and higher salinity). Such technological advances would make more reservoirs technically amenable to the economic application of chemical treatment processes. However, even with advanced technology, the number of polymer flooding and profile modification projects would not be not significant relative to the combination processes.

Figure V-5

Incremental Reserves by ASR Process Implemented Technology vs. Advanced Technology

Figure V-6 displays the projected annual production that could result from ASR technology advances for oil prices of \$16/B and \$32/B from the analyzed Illinois reservoirs. In both cases, a small, but significant, incremental amount of oil could be added to the state's production over the next 25 years. At \$16/B, yearly production would still be increasing by the year 2020, reaching as high as 1.7 million barrels in that year (1.3 million barrels of which is attributable to technology advances). At \$32/B, production would peak in the year 2016; advances in ASR technology would contribute 0.3 million barrels per year, 14% of the 2.2 million barrel per year peak.

3. Effects on State Revenues and Economic Activity

As in the implemented technology scenario, state corporate income taxes could make the largest contribution to state and local revenues, accounting for 50% to 75% of the additional direct state tax revenues at each analyzed oil price (Figure V-7A). At an oil price of \$16/B, ASR technology advances could account for \$35 million (78%) of the \$45 million in total potential state revenues. At oil prices of

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	0	1	0	0	12	60	12	61
\$20	0	8	43	0	13	62	56	70
\$24	0	8	45	0	13	62	58	70
\$28	0	8	47	0	13	63	60	71
\$32	0	8	47	0	13	63	60	71
\$36	0	8	47	0	13	64	60	72

* This is the total reserves from 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	0	1	0	0	2	8	2	9
\$20	0	2	3	0	3	9	6	11
\$24	0	2	4	0	3	9	7	11
\$28	0	2	5	0	3	9	8	11
\$32	0	2	5	0	3	9	8	11
\$36	0	2	5	0	3	12	8	14

Figure V-6

Annual Production from ASR

Implemented Technology vs. Advanced Technology

A) At \$16/B

B) At \$32/B

\$24/B and higher, \$20 million to \$25 million in additional direct state revenues could be attributable to advances in technology, leading to a total direct state revenue potential of \$80 million to \$120 million.

Illinois could also benefit from the stimulation of additional in-state economic activity by advanced technology ASR activities; however, advances in ASR technology only marginally increase state economic activity relative to the implemented technology case at oil prices above \$16/B (Figure V-7B). At \$16/B, ASR technology advances could add over \$550 million to state economic activity, for a total of over \$700 million. At higher oil prices, \$44 million to over \$112 million (4% to 10%) of the \$870 million to \$1.3 billion in additional state economic activity could be attributed to advances in ASR technology.

4. Effects on the National Economy and Budget

The development of advanced technology for recovery of the known UMO resource in the state of Illinois could also benefit the nation. An additional 60 to 70 million barrels of reserves could replace imports and enhance the nation's energy security and independence. The additional reserves could also have an economic impact at the national level.

Application of advanced ASR technology would significantly increase direct Federal revenues, specifically through increases in corporate and personal income tax receipts (Figure V-8A). At oil prices below \$32/B, technology advances account for between \$20 million and \$40 million of the \$60 million to \$260 million in additional direct Federal revenues. At oil prices of \$32/B and \$36/B, the additional direct Federal revenues could be even higher as the EOR tax credit (which can be applied to the use of polymer gels and foams in ASR processes) begins to phaseout. ASR technology advances could contribute from \$80 million to over \$110 million in direct Federal revenues for a total potential of over \$450 million in direct Federal revenues from advanced technology ASR activities.

To the extent that each additional barrel of domestic oil production replaces a barrel of imports, the foreign trade deficit could be reduced as the value of the produced oil is spent domestically rather than abroad. The avoided imports due to advanced technology ASR could be most substantial at \$16/B (Figure V-8B). At this oil price, ASR technology advances could contribute over \$780 million (80%) of the \$975 million of avoided imports. At higher oil prices, the increment due to technology advances could be between \$300 million and \$450 million of the \$1.4 billion to \$2.6 billion in total replaced imports.

Figure V-7

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-8

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.

D. CONCLUSIONS

As discussed in Chapter III, 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 field applications. At an oil price of \$20/B, implemented technology EOR and ASR process could contribute over 55 million barrels to Illinois' reserves base. At \$28/B, potential incremental reserves could reach over 70 million barrels.

Advances in technology could significantly increase the potential incremental reserves and associated economic benefits which are possible using implemented technology EOR and ASR. Technology advances could increase implemented technology incremental reserves by over 20%, adding 15 million barrels of oil, at an oil price of \$20/B. The total potential at this price, over 70 million barrels of incremental reserves, is nearly 55% of Illinois 1991 proved reserves. At an oil price of \$28/B, technology advances could stimulate over 70 million barrels of incremental reserves for a total EOR and ASR potential of over 140 million barrels. If this potential were to be realized, advanced technology EOR and ASR could more than replace Illinois 1991 proved reserves.

The activities associated with advanced technology EOR and ASR would generate substantial direct state tax revenues. At \$20/B, \$18 million of the \$66 million of potential direct state revenues are attributable to technology advances. At an oil price of \$28/B, over 55% (\$118 million) of the \$206 million 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, large portions of the oil resource will remain unrecovered in the analyzed reservoirs (Figure V-9). At the improbably high oil price of \$36/B, total ASR reserves potential would be 72 million barrels while EOR reserves potential would total 71 million barrels. If this reserves potential were realized, over 680 million barrels of mobile oil (91% of the mobile oil target) and 2.6 billion barrels of immobile oil (97% of the immobile oil target) would remain in analyzed Illinois reservoirs. In addition, over 2.2 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 5.5 billion barrels is the target for further advances in EOR and ASR technologies.

Figure V-9

Illinois Remaining Oil Resource After Advanced Technology Recovery