FOSSIL ENERGY

DOE/BC--89/6/SP
(DE89000744)

ABANDONMENT RATES OF THE KNOWN DOMESTIC OIL RESOURCE

NOVEMBER 1989

Bartlesville Project Office
U. S. DEPARTMENT OF ENERGY
Bartlesville, Oklahoma

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from the Office Of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615)576-8401, FTS 626-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161

Price: Printed **A03**
Microfiche A01

DOE/BC—89/6/SP
Distribution Category UC-122

ABANDONMENT RATES OF THE KNOWN DOMESTIC OIL RESOURCE

U. S. DEPARTMENT OF ENERGY

BARTLESVILLE PROJECT OFFICE

NOVEMBER 1989

ACKNOWLEDGEMENT

This report was prepared by ICF-Lewin Energy for the U. S. Department of Energy, Bartlesville Project Office, under contract number DE-AC19-86BC14000. Any questions or comments on this report should be directed to R. Michael Ray of the Bartlesville Project Office (918/337-4403).

TABLE OF CONTENTS

LIST OF FIGURES ii

LIST OF TABLES ii

SUMMARY 1

BACKGROUND 3
- Resource Magnitude 3
- Well Abandonments 4

STUDY OBJECTIVE 6

ANALYTICAL APPROACH AND DATA SOURCES 6
- Nine States Evaluated 6
- Data Sources 7
- PI Data Limitations 9
- PI Data Analysis 9
- TORIS Data Coverage 9
- TORIS Evaluation 9

STUDY RESULTS 10
- Historical Abandonment Trends Using PI Data for Eight States 10
- Historical Abandonment Trends Using TORIS Data for Eight States 11
- Comparison of the Two Historical Analyses for Eight States 11
- Historical Abandonment Trends Using TORIS Data for Nine States 13
- Future Abandonment Trends Using TORIS Data for Nine States 13

CONCLUSIONS 14

GLOSSARY 17

APPENDIX A: ANALYSIS OF RESOURCE ABANDONMENTS BY STATE 21
- Conclusions Based on State Analyses 27

APPENDIX B: METHODOLOGY OF ANALYSIS USING TORIS AND PI DATA 28
- METHODOLOGY 29
  - PI System Characteristics 29
  - TORIS Characteristics 30
  - PI Methods of Analysis 32
  - TORIS Methods of Analysis 33
  - Comparison of Analytical Methods 36
- CONCLUSIONS 38

REFERENCES 39

LIST OF FIGURES

Figure 1. Over 300 Billion Barrels of Known Oil Resources in Reservoirs of the Lower-48 States Will Remain After Conventional Production 3

Figure 2. Oil Prices Affect Stripper Wells Almost Immediately 5

Figure 3. Historical Abandonment Trends, TORIS Analysis Versus PI Analysis (Results are Comparable for the 8 States Analyzed) 12

Figure 4. Abandonment of Remaining Oil Resource (Nine State TORIS Analysis) 13

Figure 5. Remaining Oil Resource Contained in Active Reservoirs (Nine State TORIS Analysis) 14

Figure A-1. California Remaining Resource Abandonment 21

Figure A-2. Colorado Remaining Resource Abandonment 22

Figure A-3. Kansas Remaining Resource Abandonment 23

Figure A-4. Louisiana Remaining Resource Abandonment 24

Figure A-5. New Mexico Remaining Resource Abandonment 24

Figure A-6. Oklahoma Remaining Resource Abandonment 25

Figure A-7. Texas Remaining Resource Abandonment 26

Figure A-8. Wyoming Remaining Resource Abandonment 26

LIST OF TABLES

Table 1. Original and Remaining Oil Resources in Nine States Analyzed 7

Table 2. Comparison of PI and TORIS Estimates of Cumulative Abandonments for Eight States 11

Table B-1. Extent of Data Coverage for TORIS Evaluation Based on Original Resource Contained in the Nine Major Oil-Producing States Analyzed 31

SUMMARY

After currently proved reserves are produced by conventional methods, nearly two-thirds of the known domestic oil resource — more than 300 billion barrels — could be abandoned in reservoirs in the Lower-48 United States. This resource is not economically recoverable with currently available technologies. Production of any meaningful portion of this oil will require both adequate oil prices and technology advances in such areas as reservoir description and secondary and tertiary recovery. Cost-effective application of such new or improved technologies now depends largely upon the use of existing wells as points of access to the reservoirs containing the remaining oil resource. Existing U.S. wells, however, are being plugged and abandoned at record rates, which impairs economic access to this remaining resource.

This study was designed to estimate the amount of known remaining oil resource associated with abandoned wells and to project future abandonments as a function of oil prices. Two independent analytical approaches, applied in eight oil producing states, show an accelerating rate of resource abandonment:

- Nearly 30% of this resource had been abandoned in eight major oil producing states by 1980.

- By 1987, 40% of this resource had been abandoned, with the rate of remaining resource abandonment increasing in more recent years.

Future rates of abandonment, projected in nine major states, are highly sensitive to oil prices:

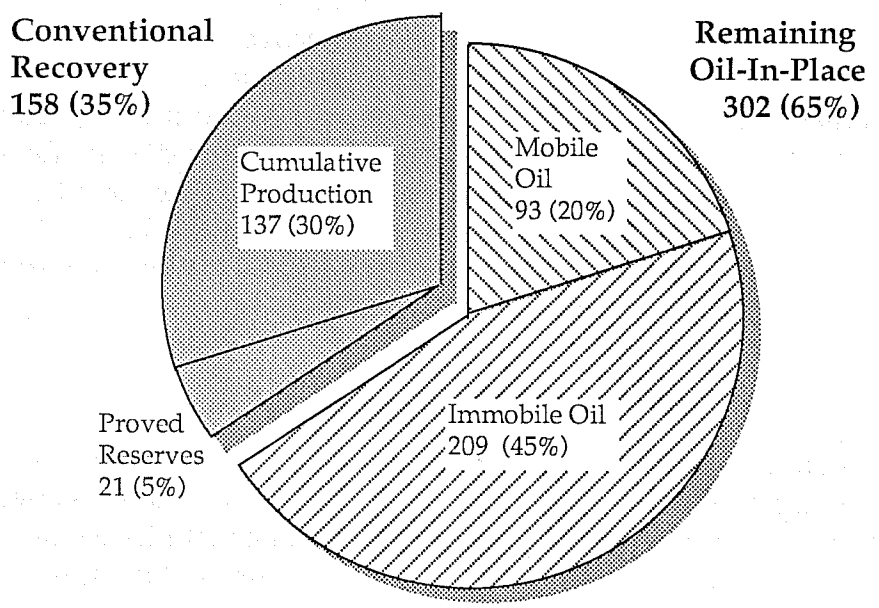
- If low oil prices persist and technology advances are delayed, remaining resource abandonments in the Lower-48 states could reach 65% by 1995 and exceed 75% early in the twenty-first century.

- Even if oil prices return to the record high levels of the early 1980s, nearly 60% of the resource could be abandoned by 2000.

This report can serve as a precursor to an analysis of the potential impact of abandonments on the application of advanced recovery methods. The cost impact of drilling new wells could delay the implementation of a recovery process or possibly eliminate some opportunities for such applications. The results of this study, coupled with additional reservoir analyses to identify potential areas of advanced recovery opportunities, can be used to estimate the resource base that is at risk. The results of such an analysis could be used to focus short term work on methods to delay abandonment in these high risk areas and thereby increase opportunities for additional recovery. In many cases, the application of existing technology in new locations or novel ways in marginal fields may be appropriate. Research should proceed to identify methods to reduce costs in advanced recovery operations, allowing for timely utilization of wells that are approaching abandonment. Furthermore, in light of the increase in well abandonments, research to identify methods to reduce costs associated with redrilling abandoned wells or re-entering plugged wells may help to increase the economic accessibility to the remaining resource.

Resource Magnitude

Current U.S. oil production can only satisfy roughly 60% of domestic demand, requiring imports to fill the gap. While this might indicate a critical shortage of domestic oil, the U.S. actually has a vast resource of oil in known reservoirs. Domestic production, not resource, is in shortage. As of the end of 1985, 460 billion barrels of original oil in place (OOIP) have been found in known reservoirs in the Lower-48 states, excluding the 33 billion barrels of original oil discovered in Alaska. Of this Lower-48 resource, 137 billion barrels have already been produced, and another 21 billion remains as proved reserves, oil that can be economically recovered with current technology (Figure 1).



Lower-48 Total: 460 Billion Barrels Original Oil-In-Place*

Source: BPO/TORIS, 1987; EIA, 1986

* As of 12/31/85.

Figure 1: Over 300 Billion Barrels of Known Oil Resources in Reservoirs of the Lower-48 States Will Remain After Conventional Production

The remaining two-thirds of the known resource, approximately 300 billion barrels, cannot be economically produced with currently available technology. This oil is trapped or bypassed by conventional recovery techniques due to heterogeneities and rock and fluid properties within the reservoir. The remaining resource falls into two categories: mobile oil that can be recovered through natural reservoir forces or displaced by water and recovered using improved primary and secondary recovery techniques such as advanced waterflooding and infill drilling; and immobile oil that is residual to secondary recovery processes and can only be recovered using enhanced, or tertiary, oil recovery processes such as thermal recovery, miscible gas injection, or chemical flooding. Furthermore, mobile oil consists of bypassed oil that is recoverable by advanced waterflooding and uncontacted oil that is not in pressure communication with any wells, but is producible with infill drilling. See the Glossary for a more indepth discussion of the components of this resource.

Although this remaining resource can never entirely be recovered, it represents a substantial target for future advanced techniques that are expected to become available for cost-effective application through research and development. Recovery of even a small percentage of this remaining oil could significantly augment domestic proved reserves, increase domestic production, reduce dependence on imported oil, and reduce the trade deficit. Recent estimates indicate that as much as 100 billion barrels of oil could become economically recoverable with advanced recovery processes, given research and development (R&D), technology transfer, and economic conditions adequate to promote widespread field application of these processes.*

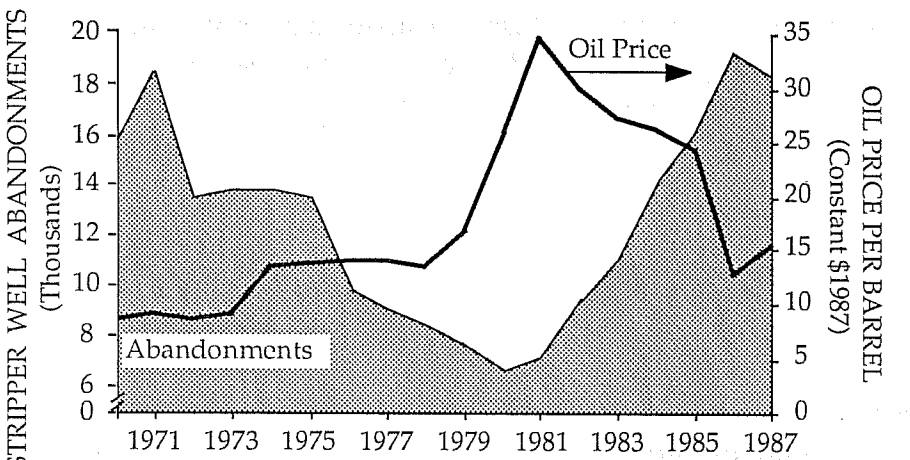
Well Abandonments

A significant portion of this recovery potential presupposes that existing wells will be available for use in advanced recovery processes. However, with a loss of economic viability caused by declining rates of production due to the maturity of the Lower-48 resource and lower oil prices, the wells that currently provide access to the remaining resource are being abandoned. These wells cannot continue to economically justify production; the cost to operate them is greater than the oil revenue they generate.

*From NPC, *Enhanced Oil Recovery*, Washington, D.C., 1984; and William L. Fisher, Director, Bureau of Economic Geology, University of Texas at Austin, *Technical Dependency of U.S. Oil and Gas Resource Base*, Paper presented at the Society of Petroleum Engineers Symposium on Energy, Finance, and Taxation Policies, September 19-20, 1988.

As these marginal, or stripper, wells lose economic viability, they are plugged and abandoned by their operators. Figure 2 shows that the rate of stripper well abandonments has increased substantially since 1980, especially when the oil price has fallen. Since 1981, over 95,000 wells have been permanently plugged.

For environmental and economic reasons, when a well is abandoned, all salvageable equipment is removed, cement plugs are placed in the well, and the land is restored as close to its natural state as possible. While permanent plugging of uneconomic wells is sound economic and environmental policy, abandonment reduces the economic viability of future advanced recovery projects that could use these wells as points of reservoir access for testing, injection, and production. Existing wells are not needed for production of uncontacted oil, as a portion of this oil can be produced through new wells alone. However, the existing surface equipment and wells are still critical to the economics of most infill drilling programs. The wells provide points for testing reservoir response and act as injection wells to displace bypassed oil in previously contacted compartments. Because both uncontacted and bypassed oil will be present in most new infill projects, economics usually demand production of both components of mobile oil to support the required investment.



Source: IOCC, 1988; OGJ Database, 1988; Dept. of Commerce, 1988

Figure 2: Oil Prices Affect Stripper Wells Almost Immediately

After abandonment, only two options exist for contacting remaining resource in a reservoir — drilling new wells and re-entering plugged wells. In either case, the operator must replace the

infrastructure that was dismantled when the original wells were abandoned. Both of these processes are extremely expensive as their costs are comparable to those for beginning production in a new field. Often re-entry is more expensive than redrilling, particularly in older, shallow fields.

As abandonments erode access to the remaining resource, fewer future advanced recovery projects will be economically feasible. Advanced recovery projects will seldom be able to produce enough oil to justify both the high start-up costs associated with applying these processes and the costs of redrilling an abandoned field.

STUDY OBJECTIVE

The objective of this study is to estimate the volume of remaining resource that has been abandoned due to well plugging and to project this volume into the future *across a range of possible future oil prices*. The results of this study can be considered a precursor to a more detailed analysis to estimate potential impacts on future production due to the necessity of redrilling otherwise promising, abandoned reservoirs.

While well abandonments can be monitored with existing data, as done by the National Stripper Well Association, the amount of remaining oil resource associated with all abandoned wells has not been previously estimated. Such an estimate is important because of the impact that loss of near-term economic accessibility may have on potential production from existing reservoirs. Significant portions of this resource are targets for future production by advanced technologies that are still undergoing research.

ANALYTICAL APPROACH AND DATA SOURCES

Nine States Evaluated

Specific states were analyzed independently to contrast resource abandonment rates across the full range of maturity exhibited by different regions in the Lower-48 states. The analysis included the following nine major oil producing states: California, Colorado, Illinois, Kansas, Louisiana, New Mexico, Oklahoma, Texas, and Wyoming. These states were chosen for their magnitude of resource, relative comprehensiveness of data, and diversity of maturity. As shown in Table 1, they account for 83% of the original oil in place and over 75% of the remaining oil resource in the Lower-48 states. The data in publicly available sources on oil

production, well counts, and oil resources for these states are reasonably complete.

These states span the range of maturity of the Lower-48 resource. Although the entire resource in the Lower-48 states could be considered mature, different areas are at varying degrees of maturity. The remaining resource in states not analyzed consists of older reservoirs that are closer to economic abandonment in the eastern U.S. and more recently discovered reservoirs that are further from their economic limit of production in western states. While the included states are qualitatively similar to the full Lower-48, this study does not explicitly extrapolate to the full resource. Also, this analysis explicitly excludes the unique Alaskan resource, the abandonment of which lies further in the future.

Table 1: Original and Remaining Oil Resources in Nine States Analyzed (Billion Barrels)

State	Original Oil-in-Place	Cumulative Production	Remaining Reserves	Remaining Oil-in-Place
California	84.7	20.8	5.8	58.1
Colorado	4.3	1.4	0.2	2.7
Illinois	9.1	3.2	0.1	5.8
Kansas	16.3	5.3	0.4	10.6
Louisiana	41.2	22.7	2.6	15.9
New Mexico	14.9	5.2	0.7	9.0
Oklahoma	39.0	12.7	0.9	25.4
Texas	154.7	57.4	7.9	89.4
Wyoming	16.7	5.1	1.0	10.6
Total, 9 States	380.9	133.8	19.6	227.5
Other States	79.1	3.2	1.7	74.2
Lower-48 States	**460.0**	**137.0**	**21.3**	**301.7**

Data Sources

For cross validation, this study used two independent methods based on unique data:

- Petroleum Information (PI) data to estimate the volume previously abandoned, cumulatively through 1980, and annually from 1981 to 1987; and

- Tertiary Oil Recovery Information System (TORIS) data to estimate historical data for the period 1985 to 1987, allowing direct comparison to the results of the PI data analysis, and to project resource abandonments from 1988 to 2015 at four oil price levels.

PI is the only cost-effective, multi-state system available to quantify actual historical abandonment rates. It reports data on past abandonments on a lease basis. PI data cannot be used to project future abandonments without numerous assumptions about oil prices and the volume of resource associated with specific wells. TORIS can evaluate both past abandonments and future rates of abandonment by analyzing the effects of oil prices on cumulative abandonment and rate of abandonment. TORIS permits explicit calculation of the remaining oil on a reservoir-by-reservoir basis at specific oil prices, so it avoids the assumptions necessary for projecting PI data.

The two sets of estimates have somewhat different interpretations because of the way abandonment is defined. PI data, organized on a lease basis, produce a *lagging* estimator of true abandonment, as PI considers the lease abandoned only when the *last* well on the *lease* is plugged. Much of the remaining oil in the lease would be abandoned before this time, as other wells are shut-in and ultimately plugged before the final well is abandoned. Therefore, much of the resource in the lease is effectively abandoned before the lease as a whole is deemed abandoned. Abandonments based on PI data, then, are low-side estimates of actual abandonments. By contrast, TORIS estimates are *leading* indicators of true abandonment. TORIS considers the reservoir abandoned when the *average* well in a *reservoir* is permanently shut-in. Poorer-than-average wells will have been plugged by this time and better-than-average wells will continue to produce beyond this point, although the reservoir as a whole is considered abandoned for the purposes of this analysis. Abandonments based on TORIS analysis, then, are high-side estimates, particularly in the near term. Because abandonment is a cumulative phenomenon, however, estimates based on PI or TORIS data and true abandonments will tend to converge over time.

Both data sources have limitations and missing data. States were analyzed in several ways to account for data discrepancies while allowing direct comparison and evaluation of the two approaches on a common basis. The methodology is discussed in detail in Appendix B.

PI Data Limitations

Because PI did not collect data for California prior to 1979, PI results include only the remaining eight states. PI lacks completely comprehensive data on the four (of the remaining eight) states with the more mature resource because data collection commenced relatively late in these states' production history. The data on these states, Illinois, Kansas, Louisiana, and Oklahoma, comprised only a portion of the total resource. The data as reported are therefore systematic underestimates. They were adjusted to account for the full resource of each state in consultation with PI professionals. For a complete explanation of the data adjustments, see "PI Method of Analysis" in Appendix B. The data were complete for the remaining four states, namely Colorado, New Mexico, Texas, and Wyoming. The data as reported for these states were used in this evaluation without adjustment.

PI Data Analysis

The PI information, as adjusted for missing data, provided cumulative production for each state and for abandoned and inactive leases. These production values were converted to remaining resource numbers using the state average recovery efficiency, which is the ratio of ultimate recovery to the original oil-in-place. With this assumption, the assessment of the remaining oil resource in each state and in abandoned and inactive leases were simple mathematical calculations.

TORIS Data Coverage

The TORIS analysis was limited to the nine states in this study because of current data availability. Information on these states included annual oil, gas, and water production, water injection, and well counts from 1970 to 1985. Detailed, reservoir-specific data were complete for only these nine states at the time of the study. (Such data are presently being added to the TORIS data base for the other major oil-producing states.) In these nine states, 766 individual reservoirs were analyzed. These reservoirs represent 61% of the original oil in place and 64% of the remaining oil in these states, which is over half of the original oil and 48% of the remaining resource in the Lower-48 states. As noted in Appendices A and B, these samples were considered representative of the full state in these analyses to make them comparable to the PI data.

TORIS Evaluation

The data contained in TORIS for the nine states allowed for production decline curve analysis of each reservoir. Exponential decline functions were projected through the historical production data, starting at the year of highest reported oil production. The

curve that demonstrated the best fit with the actual data was selected for this analysis. The characteristics of this curve were then used to project future levels of production.

TORIS assumes that future production continues, at declining rates, until the economic limit of production, the minimum production rate at which revenues meet or exceed production costs at a given oil price, is reached. This projection of future recovery assumes that current activities in the field to maintain or increase production are continued in the future. Reduction or expansion of these activities, including infill drilling, secondary recovery, and well workovers, could directly affect the projections.

Oil price is the major independent variable considered in the TORIS analysis. As oil prices increase, the economic limit of production is lowered and productive life is extended. Conversely, as oil prices drop, the minimum production rate necessary to keep the well profitable is raised and productive life is shortened. Although only changes in oil price were directly evaluated for the purposes of this study, changes in other factors such as tax policy, operating regulations, and technology improvements, could impact abandonments in much the same way as positive or negative changes in oil price.

Because TORIS contains detailed information on reservoir properties, cumulative recovery, and current production levels, the system can estimate recovery efficiency on a reservoir-by-reservoir basis. Original oil-in-place was converted to remaining oil-in-place, or remaining resource, by deducting the cumulative production to date plus the estimated additional conventional recovery, which was determined from the decline curve analysis. TORIS estimates, therefore, provide a direct measure of remaining resource abandonment in each reservoir evaluated in this study.

STUDY RESULTS

Historical Abandonment Trends Using PI Data for Eight States

PI data indicate that the rate of abandonment has been rising through the 1980s and has accelerated since 1985. In 1980, 30% of the known remaining oil resource was abandoned. Abandonments rose by approximately one percent of the total remaining oil resource per year from 1980 to 1985 and rose almost two percent per year from 1985 to 1987. By 1985, 36% of the domestic resource in the Lower-48 states was on inactive or abandoned leases, rising to 40% by 1987 (Table 2).

Historical Abandonment Trends Using TORIS Data for Eight States

Table 2 also shows TORIS results for the common period of 1985-1987. For the eight states analyzed by both methodologies, TORIS estimates that, as of 1985, between 28% and 47% of the resource was at or nearing the point of abandonment for oil prices of $34 and $16 per barrel, respectively. In 1985, the average oil price was approximately $25 per barrel, suggesting 36% cumulative resource abandonment, a figure consistent with the PI results. For 1987, TORIS estimates a range of 34% to 56% cumulative abandonment for the price range analyzed. For 1986, the rate of abandonment increased to approximately 4% for all four prices. Between 1986 and 1987, the rate of increase ranged between 2% at the highest price and 5% at the lowest.

Table 2: Comparison of PI and TORIS Estimates of Cumulative Abandonments for Eight States (Percent of Remaining Oil-In-Place)

Methodology	1985	1986	1987
PI	36	38	40
TORIS			
$16/barrel	47	51	56
$22/barrel	39	43	44
$28/barrel	33	36	39
$34/barrel	28	32	34

Comparison of the Two Historical Analyses for Eight States

The results of the two analyses are consistent over the time frame for the eight common states evaluated (Figure 3). The results were found to be essentially identical for 1985 when the oil price was $25 per barrel, after the recent peak of $34 per barrel in 1981 and a steady decline to that price in 1985. In 1986, however, oil prices collapsed, dropping below $10 per barrel for a short period and averaging approximately $13 per barrel for the year. The price recovered to only $15 per barrel in 1987. The rate of increase for the PI estimate rose from one to two percent per year for 1986 and 1987, ending at 40%. Recalling that since PI records abandonments at the plugging of the last well on the lease, a lagging indicator, true abandonments were probably higher.*

*Because production is necessary to retain leases and because prices were highly volatile, some operators are known to have continued to produce at least one well per lease in order to hold their leases, even where these operations were unprofitable, in hopes of further recovery of oil prices.

By contrast, the TORIS estimate for the oil price of $16 per barrel was 56% in 1987, a figure substantially higher than the PI estimate. In estimating when the *average* well in these reservoirs would be abandoned, a leading indicator, TORIS anticipates or overstates true abandonments by the difference in productive life between the average wells that are abandoned and the better-than-average wells that still produce and maintain access to the portion of the resource surrounding them. Nonetheless, worse-than-average wells will have been abandoned before the TORIS definition. The TORIS estimates might be interpreted as indicators of approaching abandonment while the PI estimates might be considered indicators of accomplished abandonment.

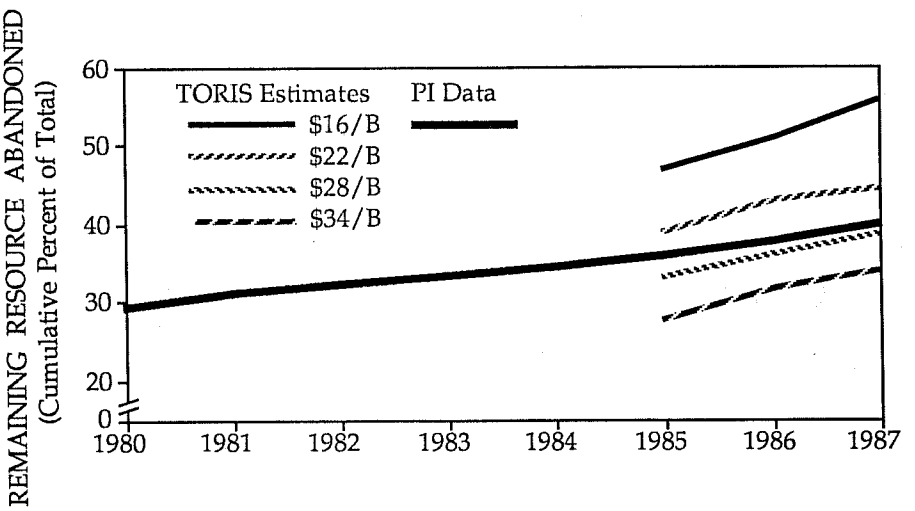


Figure 3: Historical Abandonment Trends, TORIS Analysis Versus PI Analysis (Results are Comparable for the 8 States Analyzed)

The difference between the two sets of estimates can be explained by their necessarily different definitions of abandonment. TORIS is based on analysis of reservoir units while PI is based on leases, which are generally subsets of reservoirs. Moreover, TORIS leads true reservoir abandonment and PI lags true lease abandonments. These distinctions account for near-term TORIS projections exceeding PI estimates. Actual abandonments would be bounded by these two cases. Thus, when leads and lags are considered, the results of the two independent analytical systems are actually quite consistent.

Historical Abandonment Trends Using TORIS Data for Nine States

Including California in the TORIS analysis reduces the estimates of abandonment because of California's relative immaturity as a producing region. Even accounting for California, the results indicate that over half of the domestic resource could be nearing abandonment at the $16 per barrel price level. Actual abandonments have not yet reached this mark because true abandonments lag behind TORIS results. Nevertheless, even including the large, relatively immature Californian resource, the analysis suggests that, with current oil prices, economic access to at least two of every five barrels of the remaining resource in the Lower-48 states has been, or very quickly will be, abandoned.

Future Abandonment Trends Using TORIS Data for Nine States

TORIS predicts future rates of abandonment to continue the historical trends reported by the two analyses. Figure 4 displays TORIS projections for the 146 billion-barrel remaining resource analyzed in this study. With oil prices between $16 and $22 per barrel, TORIS projects that 50% of the resource analyzed will be inactive or abandoned by 1990. If oil prices remain at current levels of approximately $16 per barrel, as much as three-fourths of the resource could become economically inaccessible by early in the twenty-first century.

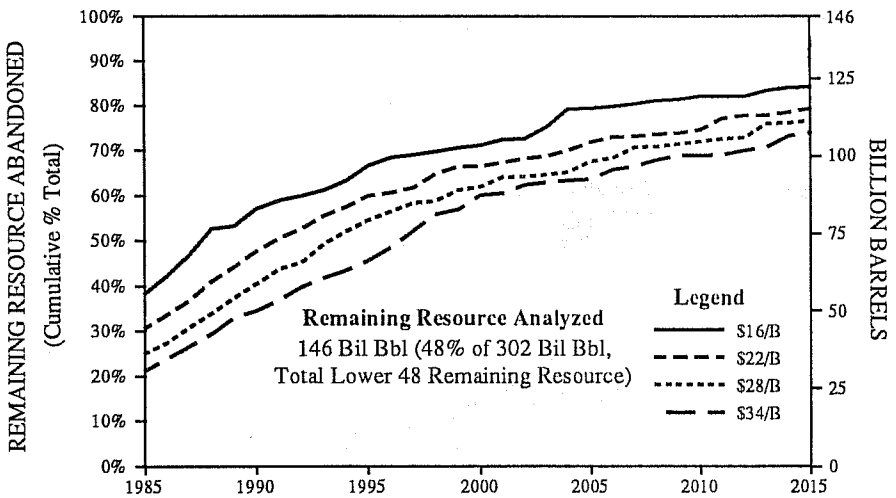


Figure 4: Remaining Oil Resource Abandonment (Nine State TORIS Analysis)

Higher oil prices can delay, but not eliminate, resource abandonment. An immediate and sustained return to the historically high

oil prices of the early 1980s will only postpone abandonments by about ten years; wells associated with more than half the resource would still be abandoned before the year 2000. At $34 per barrel, the annual abandonment rate ranges between two and three percent, a rate only slightly lower than that at lower prices. While abandonments are delayed by prices close to historic highs in the near term, they eventually rise to almost the same level expected with lower prices.

In the near term, therefore, TORIS analyses indicate that the abandonment rate is likely to accelerate. With continued low oil prices, many reservoirs will reach their average economic limit of production in the next five years.

CONCLUSIONS

Based on detailed analysis of available data from two independent sources, at least 40% of the known remaining oil resource in the Lower-48 states already resides in inactive or abandoned areas of domestic reservoirs. Moreover, this figure is projected to rise to 50% by 1990 and to over 75% early in the next century if oil prices remain depressed, indicating a rapidly accelerating abandonment rate. If oil prices rise, the rate of abandonment will slow, but will not reverse. Figure 5 shows that economic access to 50% or more of the remaining resource will be maintained only through the next decade, even at oil prices that are double the current level.

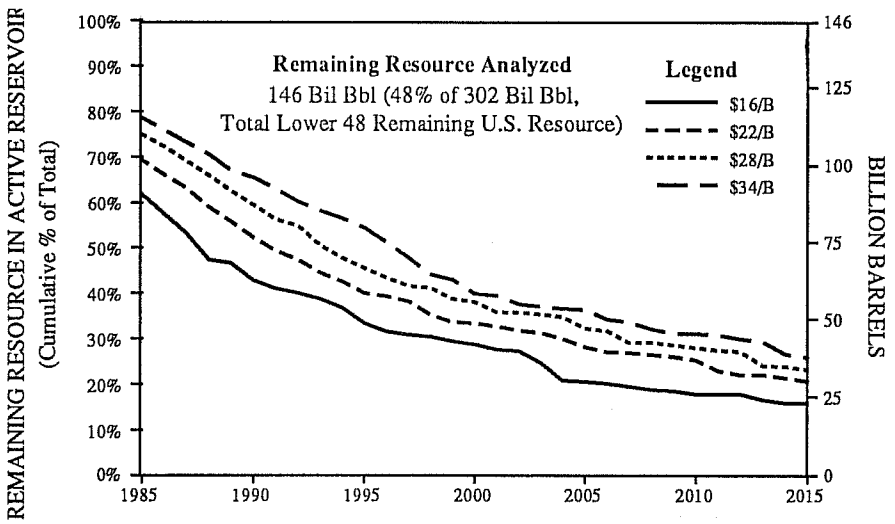


Figure 5: Remaining Oil Resource Contained in Active Reservoirs (Nine State TORIS Analysis)

As the wells that provide access to the oil resource remaining after conventional recovery are plugged, the potential for future economic recovery of the oil is largely forfeited at oil prices projected in the foreseeable future. Because many advanced recovery projects cannot be justified economically if new wells must be drilled or if abandoned wells must be re-entered for testing, injection, and production, continuing abandonment will limit the potential of advanced oil recovery in both the near- and long-term.

The findings of this report can serve as a precursor to an analysis of the potential impact of abandonments on the application of advanced recovery methods. The cost impact of drilling new wells could delay the implementation of a recovery process or possibly eliminate some opportunities for such applications. The results of this study, coupled with additional reservoir analyses to identify potential areas of advanced recovery opportunities, can be used to estimate the resource base that is at risk. The results of such an analysis could be used to focus short term work on methods to delay abandonment in these high risk areas and thereby increase opportunities for additional recovery. In many cases, the application of existing technology in new locations or novel ways in marginal fields may be appropriate. Research should proceed to identify methods to reduce costs in advanced recovery operations, allowing for timely utilization of wells that are approaching abandonment. Furthermore, in light of the increase in well abandonments, research to identify methods to reduce costs associated with redrilling abandoned wells or re-entering plugged wells may help to increase the economic accessibility to the remaining resource.

GLOSSARY

Abandonment

The permanent cessation of production operations in a well, lease, or reservoir. Environmental laws require that once a property is abandoned, all equipment must be removed and all wells plugged, generally with cement, in order to insure the integrity of the reservoir and to eliminate discharge of fluids into other formations.

Conventional Production Methods

Oil recovery operations that are currently in standard use. See also: *Primary Production, Secondary Recovery Methods*

Economic Limit of Production

The minimum oil production rate at which a well can continue to operate economically. This point occurs when revenues from the produced oil equal the costs of operating and maintaining the well.

Enhanced (Tertiary) Oil Recovery (EOR)

The third level of oil recovery operations that extends beyond conventional recovery and produces oil immobile to water, or residual, in reservoir rock pores after conventional recovery methods are complete. These operations require the injection of gases, chemical solutions, or thermal agents into the reservoir to reduce rock or fluid bonds that hold oil in pore spaces after the application of appropriate primary and secondary methods. Future EOR techniques may include the injection of microbes or other advanced agents to alter reservoir and fluid properties in an effort to improve production.

Heterogeneity

Variability in rock properties caused by processes of deposition or later alteration of the reservoir rock that limits oil recovery in producing zones by hindering fluid flow. Heterogeneity can occur both horizontally and vertically.

Immobile Oil

The part of the resource that is not displaceable by further injection of water and is therefore residual to secondary recovery methods. This oil is the target for enhanced or tertiary recovery methods. See also: *Remaining Oil Resource*

Inactive

A previously producing reservoir, lease, or well that is not currently producing. Inactive wells generally must be plugged within one year.

Infill Drilling

Drilling of additional wells in a known, developed field to increase or accelerate oil recovery. The process adds new wells between and around existing wells to reduce the average spacing. Infill drilling increases the production rate, producing proved reserves faster. However, recent studies have indicated that the reduction in well spacing also increases ultimate recovery, converting some previously unrecovered mobile oil into proved reserves, and ultimately, into production.

Lease

An oil-producing property that is legally obligated by the lessor, usually the land owner, to the lessee, an oil company or operator, for the production of oil. Normally, leases will be held for a short period of time, the primary term, during which only rental payments are required. After the primary term is expired, the lessee holds the property by continuing production and paying royalties on the oil produced.

Miscible

Able to be mixed or to form a single phase solution. In this context, miscible solvent, usually a gas, is injected in the reservoir to mix with oil, reducing viscosity and interfacial tension between the rock and the oil, and thus, increasing recovery. See also: *Enhanced Oil Recovery*

Mobile Oil

The part of the resource that is displaceable by (mobile to) water. This resource consists of oil in isolated reservoir compartments, uncontacted oil, that can be produced by primary recovery once it is contacted by a well. Additional mobile oil is bypassed by secondary recovery methods and requires additional wells and expanded fluid injection projects to be produced. A significant portion of the mobile oil resource is produced by conventional recovery operations. Cumulative production and proved reserves in most reservoirs account for a large part of the mobile oil. Unrecovered mobile oil is the portion of the resource remaining after conventional recovery and is a target for infill drilling and advanced secondary recovery methods.

Original Oil in Place (OOIP)

The amount of oil originally contained in the reservoir prior to any recovery. This oil is the overall target resource for all recovery operations — past, current, and future.

Plugging

The permanent abandonment of a well, often called plugging and abandonment (P&A). The process includes recovery of all salvageable equipment and the placement of permanent cement plugs in the well. Plugging is required to insure the integrity of the individual reservoir strata, to prevent contamination of fresh water aquifers, and to restore the surface location to its original conditions. See also: *Abandonment*

Primary Production

Recovery operations that rely solely on natural displacement forces acting within the reservoir, such as expansion of dissolved gas, expansion of an associated gas cap, and natural water incursion (water drive).

Proved Reserves

Crude oil that geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions.*

Remaining Oil Resource

The portion of the resource that remains at the completion of conventional recovery operations. This resource is the original oil less ultimate recovery, that is, cumulative oil production to date and proved reserves. It is the target for future recovery operations and consists of mobile and immobile oil.

Reservoir

An oil-bearing geological formation, generally consisting of sandstone or carbonate rocks, having properties that allow production of some portion of the oil it contains.

Resource

Total volume of oil in the reservoir; a target for recovery operations. Only a portion of the resource can be converted to proved reserves and produced. The remainder is left in the reservoir. See also: *Proved Reserves, Remaining Oil Resource, Original Oil in Place.*

Secondary Recovery Methods

Production methods that require the injection of fluids, usually water or natural gas, to pressurize the reservoir and displace mobile oil that remains after primary production.

Shut-in

The cessation of production activities for a well, lease, reservoir, or field. In this context, a well is shut-in when it is no longer profitable to operate. Ultimately shut-in wells are required to be plugged within a specified time period.

* EIA, *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves*, Washington, D.C., 1988, p. 103.

Stripper Wells

Stripper wells are low-production oil wells that have produced at an average rate of 10 barrels of oil per day or less for a 12-month period. These wells are the most economically marginal wells and the first to be shut-in when oil prices drop. They often produce large quantities of associated water, particularly in mature secondary recovery projects.

Tertiary Oil Recovery

See *Enhanced Oil Recovery*

APPENDIX A

ANALYSIS OF STATE RESOURCE ABANDONMENT

The findings of this report are based upon the evaluation of resource abandonment trends in nine major oil-producing states. The methodology used is described in Appendix B. The results from the TORIS analysis are presented in Figures A-1 through A-8 for the respective states. The impact on resource access in each state is discussed below.

California

Total Remaining Resource: 58.1 Billion Bbl
Remaining Resource Analyzed: 41.5 Billion Bbl (71%)

The TORIS results indicate that California reservoirs will be abandoned at a rate slower than the national average. Currently, between 5 and 20% of the resource is at or near the economic limit of production. Major resource abandonments are projected to occur in California after the turn of the century. Over the range of oil prices analyzed, from $16 to $34 per barrel, the abandonment rate curves shift by about 10 years. Historical production data from PI cover only the period since 1978. Because suitable data could not be found to consistently evaluate the historical lease abandonments in California, the state was not analyzed under the PI portion of the study.

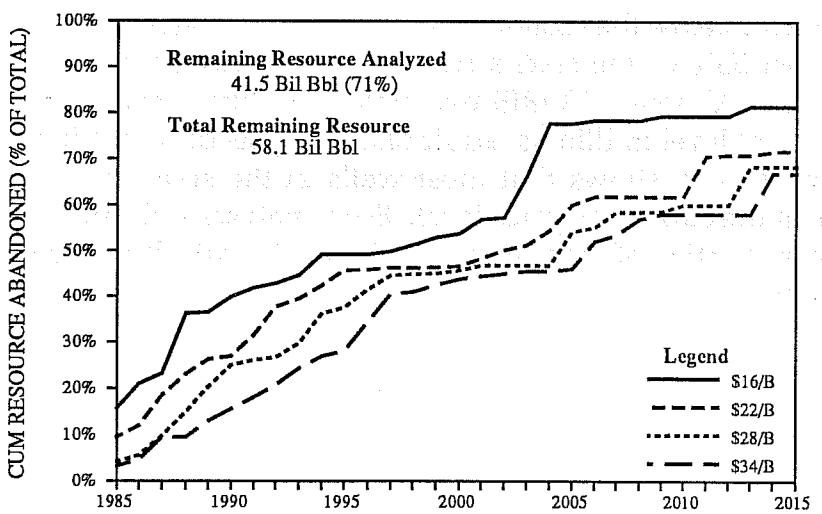


Figure A-1: California Remaining Resource Abandonment

Colorado

Total Remaining Resource: 2.7 Billion Bbl
Remaining Resource Analyzed: 0.9 Billion Bbl (33%)

The results in Colorado from both analytical methods are consistent. The Colorado remaining oil resource will be abandoned more slowly than the national average. Both PI and TORIS estimate that approximately 10% of the remaining oil in the state has been abandoned or is currently inactive. This percentage could quickly jump to over 30% by the mid 1990s, but major reservoirs in the state should not drop below the economic limit of production within the next 25 years, even if oil prices remain low.

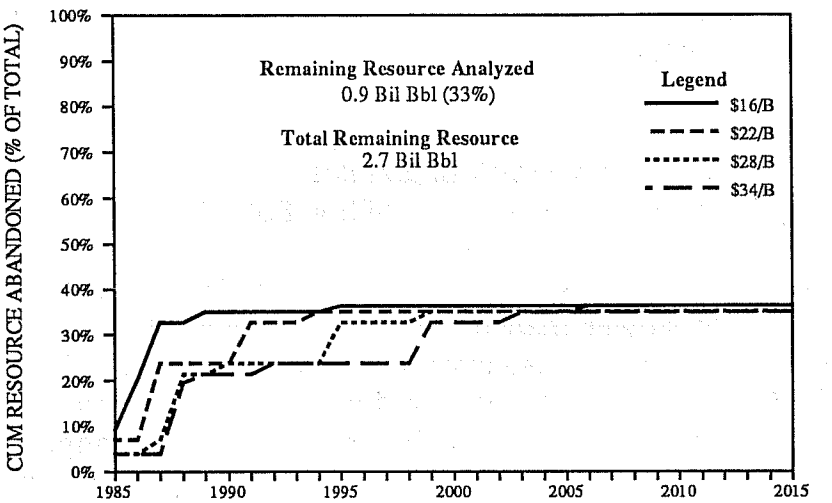


Figure A-2: Colorado Remaining Resource Abandonment

Illinois
(Not Displayed)

Total Remaining Resource: 5.8 Billion Bbl
Remaining Resource Analyzed: 2.8 Billion Bbl (48%)

The TORIS analysis shows that nearly all current production in Illinois is at or below the economic limit. The PI analysis indicates that at least 56% of the state's resource is not currently under production. Although TORIS overstates the likely short-term abandonment level in Illinois, additional analysis of recent individual production shows that most wells in the state are very marginal at the current oil price level. Both analyses indicate that a significant portion of the resource in Illinois is critically close to abandonment.

Kansas

Total Remaining Resource: 10.6 Billion Bbl
Remaining Resource Analyzed: 5.7 Billion Bbl (54%)

The remaining oil resource in Kansas historically has been abandoned at a rate above the national average. Both the TORIS and PI analyses indicate that over 50% of the state's remaining resource is either already abandoned or rapidly approaching the economic limit of production. The TORIS evaluation indicates that up to 80% of the remaining oil resource in Kansas is contained in reservoirs in which the average well production rates are currently subeconomic at an oil price of $22/barrel or less. The step function noted in Figure A-3 is caused by one large reservoir, containing approximately 20% of the state's remaining resource. This reservoir becomes uneconomic to produce in 1990 at an oil price of $16/B, with abandonment delayed by nearly 8 years for each $4/barrel increase in oil price. An oil price of $34/barrel would delay abandonment of this reservoir until 2015.

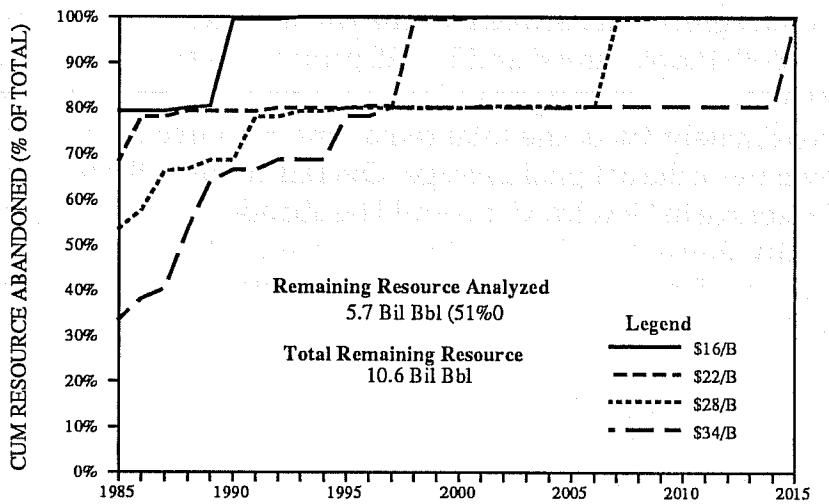


Figure A-3: Kansas Remaining Resource Abandonment

Louisiana

Total Remaining Resource: 15.9 Billion Bbl
Remaining Resource Analyzed: 7.8 Billion Bbl (49%)

The results from the two studies match closely in Louisiana. Both studies indicate that as much as 60% of the Louisiana resource is in imminent danger of abandonment. The TORIS estimate at the lowest price is only slightly lower than the historical average shown in the PI analysis over the period analyzed. The important Louisiana resource will be abandoned much faster than the national resource. Unless current trends are reversed, access to over 90% of the state's remaining resource will be lost within 20 years.

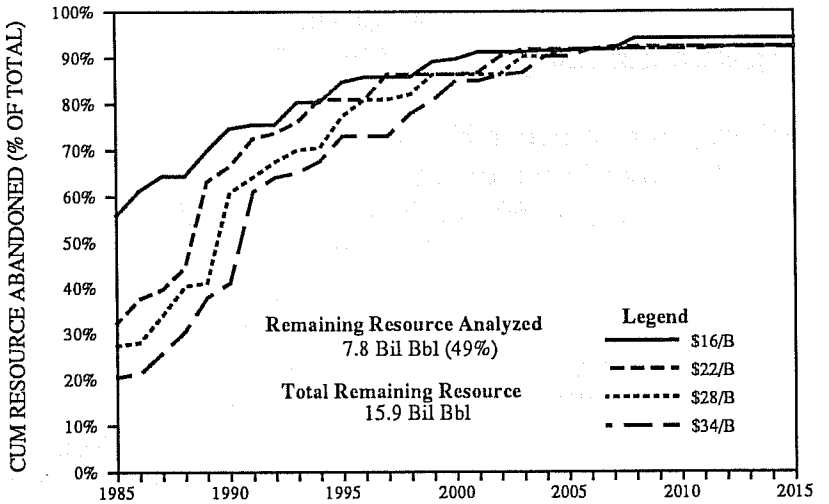


Figure A-4: Louisiana Remaining Resource Abandonment

New Mexico

Total Remaining Resource: 9.0 Billion Bbl
Remaining Resource Analyzed: 9.0 Billion Bbl (100%)

The overall agreement between results was also excellent in New-Mexico. Both the past trend and TORIS projections show that New Mexico resources are being abandoned at a very fast pace. Access to approximately 4% of the total remaining resource is lost each year, over twice the national average. Overall, though, the remaining oil resource in New Mexico should be abandoned in the future at a slightly slower rate than for the nation as a whole, as production in several large reservoirs should be maintained well into the next century.

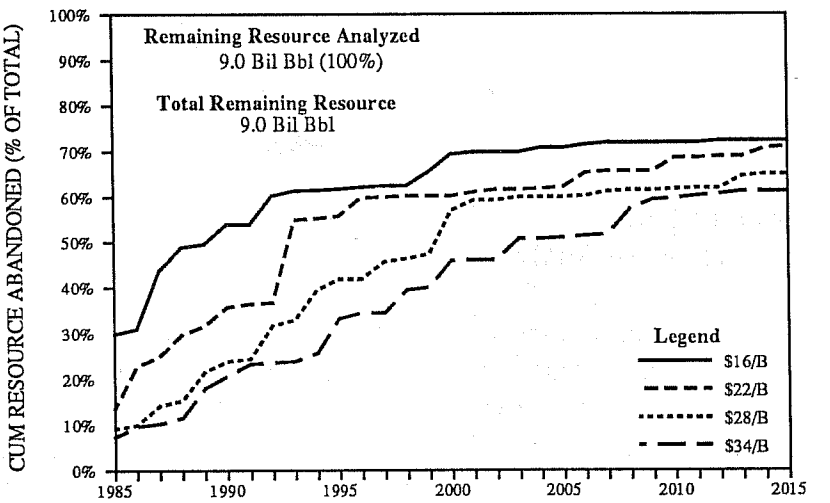


Figure A-5: New Mexico Remaining Resource Abandonment

Oklahoma

Total Remaining Resource: 25.4 Billion Bbl
Remaining Resource Analyzed: 17.9 Billion Bbl (71%)

Both PI and TORIS analyses indicate that the Oklahoma resource is economically marginal, and that significant portions have been or will soon be abandoned. The PI analysis shows that over 60% of the state's resource is currently inactive, which is equivalent to the TORIS projection at a $28/barrel oil price. If low oil prices persist, over 80% of the Oklahoma resource will be abandoned in the next 10 years, significantly more than the national average. The price sensitivity of the resource abandonment rate in Oklahoma is greater than in other states due to very "flat" decline curves in a few extremely large reservoirs.

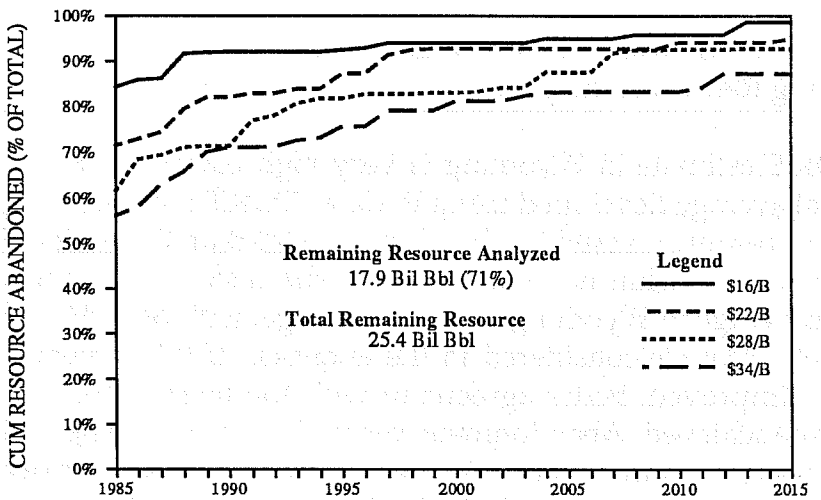


Figure A-6: Oklahoma Remaining Resource Abandonment

Texas

Total Remaining Resource: 89.4 Billion Bbl
Remaining Resource Analyzed: 55.7 Billion Bbl (62%)

The two analyses project similar abandonment rates in Texas, as both the PI data and the TORIS results at oil prices above $22/barrel indicate a 3% to 4% increase in abandonments over the past two years. As with the national analysis, the TORIS estimate at an oil price of $16/barrel was higher than the PI estimate, predicting a faster abandonment rate than is indicated by the historical trend. Both analyses indicate that the Texas resource abandonment rate will be consistent with the national average. Access to over 70% of this important state's remaining oil could be lost within 30 years, and even sooner at lower oil prices.

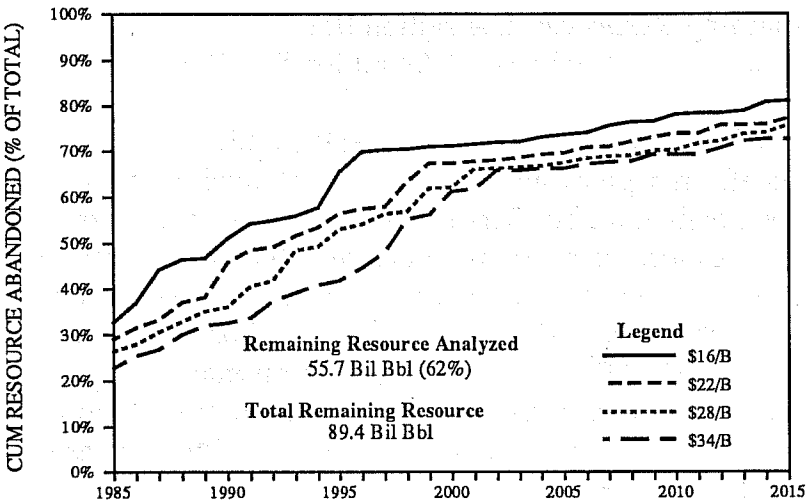


Figure A-7: Texas Remaining Resource Abandonment

Wyoming

Total Remaining Resource: 10.6 Billion Bbl
Remaining Resource Analyzed: 4.7 Billion Bbl (44%)

The TORIS estimate in Wyoming is very high compared to the historical average developed using PI data. TORIS indicates that the state's resource would be abandoned faster than the national average, a conclusion not supported by the historic PI trends. TORIS coverage in Wyoming is below average, with only 44% of the state's resource considered in the analysis. If this coverage could be improved, better agreement with the historic trend is likely to be achieved. Abandonment rates in the state are projected to decline significantly after 1990. As a result, even at an oil price of $16/barrel, lost access could be limited to close to 65% of the remaining Wyoming resource through the year 2000, 5% less than the national average at the same price.

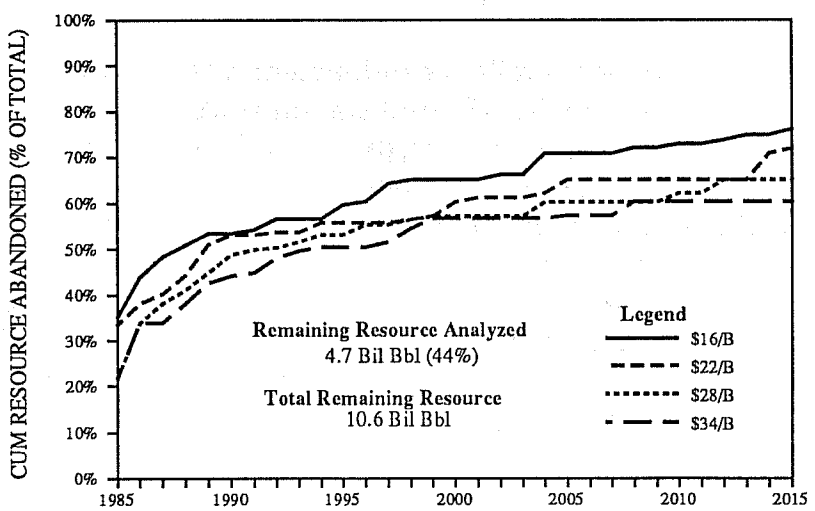


Figure A-8: Wyoming Remaining Resource Abandonment

The resource abandonment estimates developed from the TORIS analysis are reasonably consistent with the historic trends indicated by Petroleum Information System's data base. The historic TORIS estimate is vastly different from the abandonments to date calculated using PI data in only one state, Wyoming. The analyses using TORIS and PI data identified Kansas, Illinois, and Oklahoma as states with extremely high near-term resource abandonment rates. Over 50% of the remaining resource in each of these states is rapidly approaching abandonment.

Additional data enhancements would improve the capabilities of TORIS to analyze resource abandonments at the state level. The greatest difference between results generated by the two systems used in this analysis occurs in states with less than average TORIS data coverage. Production data could be obtained only for a portion of the resource represented in the data base for each state. With additional data gathering to improve the resource coverage, the TORIS analysis system would be able to provide very accurate estimates of future resource abandonments at the state level.

APPENDIX B

METHODOLOGY OF ANALYSIS USING TORIS AND PI DATA

This appendix is designed to provide technical detail on the data, models, and methodology utilized to estimate domestic resource abandonments. The methodology described here is briefly discussed in the text of the report, but the following is a more detailed, technical treatment. This appendix describes the decision process used to determine the portion of the oil resource to be analyzed, the data required to complete the study, and the various methods used to convert and analyze the information.

The analysis was conducted in response to historical trends in well abandonments. Stripper wells, economically marginal wells that produce less than 10 barrels per day on average, are being abandoned at record rates. As shown in Figure 2 in the body of the report, the magnitude of stripper well abandonments is closely tied to changes in oil prices. Given the recent drop in the price of crude oil, a large number of wells and their associated remaining resource are being abandoned as conventional recovery methods become uneconomic, causing the producing wells to be shut-in.

Although the abandonment problem has been recognized for several years, its magnitude has not been measured because there were previously no evaluation systems available to completely analyze the resource associated with the abandoned wells. While some existing data allowed speculation on the effects of abandonments, no analytically based projections had been possible.

Developing a system for evaluating resource abandonments requires significant information on the original oil-in-place in and the production of domestic reservoirs. Ideally, projections of future rates would be derived from analyses over a variety of oil price and economic conditions. The Tertiary Oil Recovery Information System (TORIS) has the data to support and is capable of conducting such an analysis. TORIS was enhanced and utilized by the National Petroleum Council (NPC) for its 1984 assessment of enhanced oil recovery (EOR) potential.* TORIS was upgraded and

*hoc. cit.

is now maintained by the Bartlesville Project Office (BPO) of the Department of Energy (DOE). The system currently contains detailed information on production, injection, and active wells for reservoirs nationwide.

In addition to the TORIS system, an independent data and analysis approach was developed as a means of verifying and contrasting the findings. This system relies on information collected and reported by the Petroleum Information (PI) Services on inactive and abandoned leases. The resource on each of these leases was calculated using the historical recovery efficiency for the state in which the lease is located. Both the TORIS and PI analysis methods have shortcomings, but by properly structuring the results, these limitations can be overcome and estimates developed from each independent system can be compared and contrasted. Within the constraints of the data and methods used in the analysis, the results represent important findings concerning the status of the domestic resource relative to abandonment.

This study analyzed the resources of nine major oil producing states: California, Colorado, Illinois, Kansas, Louisiana, New Mexico, Oklahoma, Texas, and Wyoming. These states contain over 80% of the total resource in the Lower-48 states and rank among the leaders in terms of current production levels. Good data are available on the resource and its past production in these nine states, which have been the focus of recent data collection efforts. Well counts, associated gas and water production, and operating costs have been recently updated and analyzed for these studies. Given their relatively large and well understood resource, these states were ideal for this preliminary evaluation.

METHODOLOGY

PI System Characteristics

An analytical system was established to utilize the inactive and abandoned lease information available from PI. Relevant information was available on only eight states; the data for California were complete only back to 1979 and therefore could not be analyzed on the same basis as the other 8 states, for which more complete earlier data were available. Production data for the remaining eight states were collected and processed using a consistent evaluation system. Data were available on the cumulative production from leases that were reported as inactive or abandoned for each year from 1980 to 1987. Leases are considered inactive if they had previously produced, but did not produce any oil during the

calendar year; they are considered abandoned by PI if all wells are plugged or the lease has been inactive for three consecutive years. A lease is a legal parcel of land that defines the production unit for many recovery projects. Once a lease becomes inactive, the lease agreement requires that production be restored quickly, or the lease is forfeited. At that time, all wells must be plugged and all equipment must be removed in order to restore the lease to its original condition.

The information available from PI for each state included cumulative production from active, inactive, and abandoned leases, represented in its data base. The current production data, also available for active leases, were compared with production data from the Energy Information Administration* to ensure that the PI data represented the entire, currently active state resource. Cumulative production data were compared to estimates made in 1980 by the American Petroleum Institute (API).** This comparison was critical to the analysis because API is the only available source of estimates for individual state total original oil resources. By assuring that the PI data represented the same resource volume as the API data, and adjusting the data to reflect full coverage when it did not, the resource assessment could be used to convert cumulative production to remaining resource for each state.

The PI lease data base was the only source of data that could be used to calculate historical resource abandonment trends. Other sources, which appeared to offer no significant advantage in terms of accuracy over the PI data, were determined to be too costly or time-consuming for use in this analysis. In some cases, the PI data were incomplete, particularly for the California resource, which had to be removed from this portion of the analysis. The information on other states included only cumulative production, with no direct measure of remaining resource in the leases covered. Despite these limitations, adjustments for which were incorporated in the analysis, the PI data and analysis system offered the only cost-effective alternative for accurately measuring past resource abandonments.

TORIS Characteristics

The TORIS data base contains detailed information on over 3,700 reservoirs representing over 72% of the domestic oil originally discovered in this country, including distinct rock and fluid prop-

*Energy Information Administration, *Production and Well Data Base,* Dallas, 1987.

**American Petroleum Institute, *Reserves of Crude Oil, Natural Gas, and Natural Gas Liquids in the United States and Canada,* Washington, D.C., 1980.

erties critical to describing the oil resource in each of these reservoirs.

The TORIS data, models, and methodology were used to analyze historical production trends and project probable future production from 766 individual reservoirs in the nine states considered. The well abandonment analysis was conducted on reservoirs with sufficient TORIS data to support a detailed evaluation. Each reservoir was evaluated using the models and system developed by the NPC. The data for these reservoirs were updated and enhanced to include production, injection, and well counts through 1985.

Table B-1: Extent of Data Coverage for TORIS Evaluation Based on Original Resource in the Nine Major Oil-Producing States Analyzed (Billions of Barrels Except % of Total)

State	Total OOIP*	TORIS OOIP*	Analyzed OOIP	Analyzed % of Total	Total ROIP	TORIS ROIP	Analyzed ROIP	Analyzed % of Total
California	84.7	78.1	61.4	72	58.1	43.2	41.5	71
Colorado	4.3	2.3	2.2	51	2.7	1.8	0.9	33
Illinois	9.1	5.2	4.8	53	5.8	3.6	2.8	48
Kansas	16.3	10.4	7.7	47	10.6	7.8	5.7	54
Louisiana	41.2	17.3	12.3	30	15.9	13.2	7.8	49
New Mexico	14.9	12.6	12.6	85	9.0	9.0	9.0	100
Oklahoma	39.0	27.5	27.5	71	25.4	17.9	17.9	71
Texas	154.7	107.5	96.0	62	89.4	72.0	55.7	62
Wyoming	16.7	9.2	8.0	48	10.6	6.9	4.7	44
Total 9 States	**380.9**	**270.1**	**232.5**	**61**	**227.5**	**175.4**	**146.0**	**64**
Other States	79.1	43.6	—	—	74.2	24.4	—	—
Total L-48 States	**460.0**	**313.7**	**232.5**	**51**	**301.7**	**199.8**	**146.0**	**48**

* Based on API, 1980

Based on information from the DOE, production and well counts since 1970 were determined for each reservoir. Table B-1 displays the original oil-in-place (OOIP) and data coverage achieved in assigning oil production to TORIS reservoirs in each of the states analyzed. As discussed previously, these states account for a vast majority of the original and remaining oil in place (ROIP) in the Lower-48 United States. Overall, the reservoirs analyzed represented 61% of the original oil (and 64% of the remaining oil) contained in the nine states evaluated, and over one-half of the

total original resource (48% of the remaining resource) for the Lower-48 states.

The data contained in TORIS for reservoirs in the nine states allowed production decline curve analysis of reservoirs. This system can project future resource access, while other known and tested analytical systems, including PI, cannot. Because TORIS has been has been tested and reviewed over the past several years, it provides a highly dependable system for closely evaluating the abandonment issue.

TORIS also contains detailed information on the actual resource remaining in each reservoir, providing a distinct advantage over the PI data and other analytical systems which must estimate or extrapolate the resource values from other related data elements. TORIS can also play an integral role in extending the present evaluation of the remaining resource to a projection of the actual effect of abandonments on future oil production potential.

PI Method of Analysis

The first step in this evaluation was to compare cumulative production values from the PI data base values to the 1980 API data. The comparison was used to establish the PI coverage in each state evaluated. The four states with the less mature resource, namely Texas, New Mexico, Wyoming, and Colorado, were fully covered in the data base. The other four states, Oklahoma, Kansas, Illinois, and Louisiana, were determined to be only partially covered by PI data, and steps were taken to account for the missing information. A series of assumptions were made and reviewed with managers of the PI data base; the most logical assumption that could account for the discrepancy in each state was adopted.

The cumulative production for these four states, as reported by PI, was increased to account for missing data. Two methods were considered in adjusting the cumulative production on inactive and abandoned leases. The first method assumed that the resource missing from the PI data base was and is being abandoned at the same rate as the leases represented in the data. This scenario was unlikely in the case of Illinois, Kansas, and Oklahoma because the PI data accurately accounted for all actively producing leases based on comparisons of current production levels in each state. For Louisiana, this assumption was appropriate and was used because PI data included production information on all leases,

active, inactive, and abandoned, only since 1969 and excluded all previous information.

For the other three states in which production discrepancies were noted, an alternative method was used to account for the missing data. This method assumed that the discrepancy was due to leases abandoned before the PI data base was formed. This theory, based on evaluation of the full data base used to develop the PI results and discussions with managers at PI, appeared reasonable.

The PI information, as adjusted to account for missing data, provided cumulative production for each state and for abandoned and inactive leases. These production values had to be converted to remaining resource estimates for comparison to the TORIS results, using the state average recovery efficiency, under the assumption that each lease had produced at the reported level of the state as a whole. The state average recovery efficiency was calculated by dividing the ultimate state production by the original state oil resource. With this assumption, assessing the remaining oil resource in the state and in abandoned and inactive leases is a matter of simple mathematical calculations to convert from cumulative production from abandoned and inactive leases to remaining oil in place.

The analysis of abandonments using the PI system assumes that the resource on a lease is abandoned when the last well on the lease becomes inactive or is plugged. This abandonment time is later than the actual abandonment time for a significant portion of the resource on the lease. Much of the remaining oil in the lease would be abandoned before this time, as other wells are shut-in and ultimately plugged before the final well is abandoned. The PI analysis therefore represents a low-side indicator of actual abandonments. The rates of abandonment estimated with this system lag actual rates because wells within the lease (and their associated remaining oil resource) that are abandoned over time are not reflected in the PI data until the last well becomes uneconomic to produce.

TORIS Method of Analysis

The data contained in TORIS for the nine states was used to derive a production decline curve for each reservoir. The system currently contains fifteen years (1970 through 1985) of historical production data on oil, water, and gas for each analyzed reservoir. Historical production data were used to project a series of exponential decline functions, starting at the year of highest reported

annual oil production. The various curves were evaluated, and the one that demonstrated the best "least squares" fit, through the production history was selected. The characteristics of this curve were then used to project future reservoir production levels.

Future production was estimated as a function of the demonstrated production in the recent past. For this reason, TORIS projections assume that historical operator activities to maintain and improve recovery from the reservoir are continued into the future. To the extent that historical production levels have been sustained by infill drilling, workovers, and expansion of secondary recovery within the reservoir, TORIS assumes these activities will be continued in the future at near historical rates. If these activities are significantly expanded or curtailed, the future production projections will either understate or overstate the true situation; the projections will be too low for reservoirs where recovery operations are expanded, and too high for reservoirs where improved recovery operations and maintenance activities are curtailed. In a period of rapidly falling oil prices, activity is more likely to be curtailed than expanded.

TORIS projects continued future production at declining rates until the economic limit of production is reached. This limit establishes the productive life of the reservoir based on the oil price and the estimated operating cost. The economic limit of production, the minimum oil rate at which revenues meet or exceed production costs, was calculated at various oil prices. Costs associated with producing each well were established using the regional average costs reported by EIA* for the depth and the geographic location of the reservoir. The overall operating cost projections included costs for workovers, general maintenance of well equipment, and maintenance of production equipment. These costs were adjusted to reflect the expected cost at the oil price being analyzed, based on a cost-price relationship developed by the NPC.** These costs were verified to ensure accurate prediction of actual 1987 costs. To the extent that operators can defer these activities or reduce costs by limiting or varying the type of maintenance performed, the assigned costs may be overstated. However, equipment maintenance is crucial to continued production and access to the remaining resource.

*Energy Information Administration, *Cost and Indexes for Domestic Oil and Gas Field Equipment and Production Operations*, Washington, D.C., Annuals 1977-1987.
**NPC, *op. cit.* Appendix C, p. C-1-C-4.

If new, advanced recovery activities are implemented beyond the expansion of ongoing projects, the estimates of individual reservoir production levels could become inaccurate. The effects of intensive infill development and/or the implementation of new recovery practices, such as EOR, which could increase future production potential and extend reservoir life, are not considered by these estimates. Conversely, if drilling and workover activities or expansion of existing secondary recovery activities are not continued at past levels, future production could be lower than estimated, and abandonment would occur sooner than projected. Therefore, to the extent that operating practices evolve in the future, the actual production and reservoir abandonments could differ somewhat from the TORIS projections.

Oil price is a major independent variable considered in the TORIS analysis of economic limits. As the oil price increases or operating costs are reduced by successful research, the economic limit is reduced and productive life is extended. When oil prices fall or operating costs increase due to factors such as increased regulatory activity, the economic limit increases and the productive life is shortened. Properly designed tax incentives could have the same effect as increased oil prices in extending the productive life of reservoirs. Therefore, although only changes in oil price were directly evaluated in the study, these other factors may have effects on abandonments similar to those noted with oil price shifts.

Because TORIS contains detailed information on reservoir properties, cumulative recovery, and current production levels, the system can be used to estimate recovery efficiency on a reservoir-by-reservoir basis. Original oil in place is converted to remaining oil in place, or remaining resource, by deducting ultimate recovery — the cumulative production to date plus the estimated additional conventional recovery, as determined from the decline curve analysis of the original oil in place. TORIS estimates, therefore, provide a direct measure of remaining resource abandonment in each reservoir evaluated in the study.

No attempt was made to account for missing TORIS data. The analytical results consider only the reservoirs actually evaluated during the study, which, as stated previously, account for a large majority of the remaining oil resource estimated in all reservoirs of the states analyzed. Although this analytical method is the most thorough possible evaluation of the domestic resource, the results have not been extrapolated. The resource abandonment values in this analysis are reported as calculated, converted to a percentage

of the total remaining resource in each state for analytical convenience. Given the nature of the data used and the overall coverage realized, the results should be reasonably accurate for all of the remaining oil resources in the Lower-48 states.

The TORIS evaluation system provides a high-side, or leading, indicator of resource abandonment. The analysis of production is conducted reservoirwide, and therefore considers average reservoir properties, production, and well counts. TORIS estimates the economic limit and timing of resource abandonment based on the average well in each reservoir. The abandonment of the average well precedes, or leads, the abandonment of better-than-average wells that continue to produce for some time after the TORIS projected reservoir abandonment date; access to the remaining resource associated with these wells is thus maintained after the time TORIS projects its loss. For this reason, in the near term, TORIS estimates are higher than actual abandonments, even when analyzed at the prevailing oil price.

The TORIS evaluation uses a fixed oil price analysis method and cannot account for changes in the oil price. As a result, such changes, particularly rapid increases or drops as experienced recently, will not be immediately and accurately reflected in the projected abandonment rates. Conversely, TORIS projections assume that the oil price analyzed has been and will continue to be the only price considered by operators in making production decisions. This assumption can further increase the short-term TORIS projections relative to actual abandonments in times of falling oil prices.

Despite the limitations of the system, TORIS projections provide reasonable estimates of resource abandonments, particularly over mid- to long-term time periods. Its leading nature and overestimation during times of falling oil prices will be mitigated over time, because abandonments are projected on a cumulative basis, and because operators will ultimately adjust their producing and abandonment activities to reflect changes in oil prices. While TORIS projections in the near term may overstate actual abandonments, estimates beyond the next five to ten years should begin to converge with actual abandonments.

Comparison of Analytical Methods

The projections developed for this analysis utilized two independent data and analytical approaches. The results are reasonably

consistent when they are placed on a common analytical framework. The PI analysis considered the abandoned resource for the state as a whole, assuming that the data, after adjustment for obvious missing elements, accounted for the entire state resource. TORIS estimates considered only the resource actually contained in the data base, with no adjustment for missing data or reservoirs. The results of the two approaches were placed on a common basis by converting abandonments to percentage of analyzed resource.

The results must be considered with the limitations of each system in mind. The results were not adjusted to account for the inherent lead and lag effects associated with the two methods used. Further, the resource assessments developed from the PI data may understate the actual resource on abandoned leases if the state average recovery efficiency is higher than the actual recovery efficiency of the lease. This phenomenon could have occurred on many older leases, which were abandoned before higher oil prices and new reservoir management practices helped to increase recovery potentials.

The range of values projected by TORIS over the price range analyzed and the results from the PI evaluation can be viewed as reasonable upper and lower bounds of actual abandonments to date. Future abandonments should also lie within the bounds established by the TORIS projections. The range of prices analyzed in this study should adequately account for future changes in oil prices and the leading nature of the TORIS projections.

The PI analysis considered the impact of both inactive and abandoned leases in evaluating resource abandonments. The rationale for including inactive leases is that they cannot be maintained by operators for a long period of time. After the last well is shut-in, environmental regulations require the plugging of the wells, usually within one year. The lease, if it is beyond its primary term, is legally held only by production and will therefore expire once production ceases. The TORIS projections, likewise, evaluate when the reservoir will no longer be economic to produce and must be shut-in. This inactive status will precede complete, permanent abandonment by as much as a few years. Although regulatory changes can increase the delay between a well becoming inactive and its required plugging, legal statutes and lease terms usually require abandonment activities to proceed shortly after production from the lease ceases.

CONCLUSIONS

This study evaluated the abandonment of domestic oil resources using two independent, but consistent analytical systems. The findings of the two analyses appear to be reasonably compatible when the limitations of each system are considered. The results are captured in a range of current and future levels of resource abandonments in the nine states evaluated in the study. Due to the level of coverage of the data analyzed, the results are also a reasonably accurate reflection of the abandonment situation in the entire Lower-48 state resource.

The results are consistent with other trends. The recent drop in oil prices has accelerated the rate of stripper well abandonments. Production in the Lower-48 states, which has dropped 12% in the past two years, is falling because marginal wells can no longer operate profitably and must be shut-in. The results of this analysis provide new insights into the abandonment of the domestic resource, insights not possible through simple evaluation of previously noted trends in production, well drilling, and reserve additions.

American Petroleum Institute, *Reserves of Crude Oil, Natural Gas, and Natural Gas Liquids in the United States and Canada,* Washington, D.C., 1980.

Department of Commerce, *Statistical Abstract of the United States,* Washington, D.C., 1988.

Energy Information Administration, *Cost and Indexes for Domestic Oil and Gas Field Equipment and Production Operations,* Washington, D.C., Annuals 1977-1987.

Energy Information Administration, *Production and Well Data Base,* Dallas, 1987.

Energy Information Administration, *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves,* Washington, D.C., 1986 & 1988.

Fisher, William L., Director, Bureau of Economic Geology, University of Texas at Austin, *Technical Dependency of U.S. Oil and Gas Resource Base,* Paper presented at the Society of Petroleum Engineers Symposium on Energy, Finance, and Taxation Policies, September 19-20, 1988.

IOCC, *National Stripper Well Survey,* Oklahoma City, 1988.

National Petroleum Council, *Enhanced Oil Recovery,* Washington, D.C., 1984.

Oil and Gas Journal Database, 1988.