Economic Impacts of U.S. Liquid Fuel Mitigation Options

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Disclaimer

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National Energy Technology Laboratory Forward

This study was undertaken with specific, narrowly focused objectives. It is part of a larger, ongoing effort to understand actions that could be taken, especially the potential contribution of technology, to reduce the vulnerability of the United States to future world oil price shocks. This study did not involve the use of large, complex models of either the U.S. or world economies capable of projecting fuel prices or liquid fuel production quantities should a large-scale program to produce alternative liquid fuels be undertaken. The purpose of this study was to assess the economic implications of simultaneously initiating major crash programs, on both the supply and demand sides of the economy, aimed at rapid reduction of U.S. dependence on imported oil. Whether the reader believes this type of crash program is doable, or even wise, is secondary to the purpose of the study. The report was intended to identify the infrastructure needed to actually conduct such a large undertaking. Development of such an infrastructure, including the human resources needed, is an important aspect of any effort on this scale. The results of this study provide an upper limit on what might be accomplished under the best of circumstances.

The mitigation options covered in the report and the conclusions derived are generalities and simplifications, since the range of mitigation options is not exhaustive and the timing of implementation is indeterminate. Other savings and substitute liquid fuel sources could be exploited in the United States. For example, U.S. biomass resources are significant and deserve careful analysis. Commercial ethanol and biodiesel liquid fuel production is already established and cellulosic ethanol may be capable of producing large quantities of liquid fuels. Analysis of biomass options is especially important because they represent the only renewable energy technology that may be capable of efficiently producing large amounts of substitute liquid fuels for the transportation sector. In addition, there are heavy oil resources in several western states and in Alaska that may contribute on a significant scale. A number of emerging fuel efficiency options not considered in this assessment could also have significant impact, particularly in the long-term.

All of the options considered in this report will continue to have large impacts beyond the 20-year horizon established for this analysis. Higher efficiency vehicles will continue to save liquid fuels throughout their life of another 15 years or more. It is also important to note that this study did not assume further vehicle fuel efficiency improvements after an initial eight-year period, artificially limiting the potential for the fuel efficiency options studied.

The impact of further fuel efficiency improvements after the eighth year of implementation could be significant. For example, if the average mileage efficiency of all autos and trucks continued to improve by one percent per year after the eighth year, by the end of the 20-year horizon studied, the U.S. would be saving an additional half million barrels of liquid fuels per day.

Finally, this study was not designed to address the fundamental issue of how best to reduce U.S. economic vulnerability to significant increases in world oil price. The question of whether pursuit of oil self sufficiency (through increased production of unconventional oil, coal- and biomass-based liquids, and oil shale) or decreased reliance on oil use in the U.S. economy (through enhanced vehicle fuel efficiency and conservation) is important to resolve. Production of alternative liquid fuels would not isolate the United States from global price increases because, as fungible liquid products, they would compete at the world oil market price.

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EXECUTIVE SUMMARY

The world is consuming more oil than it is finding, and at some point within the next decade or two, world production of conventional oil will likely peak. Peaking will lead to shortages and greatly increased prices and price volatility. In addition to peaking and its consequences, there are widespread concerns about the growing United States' dependence on oil imports from both an energy security and a balance of payments standpoint.

This study considered four options that the U.S. could implement for the massive physical mitigation[1] of its dependence on imported oil:

- Vehicle fuel efficiency (VFE)
- Coal liquefaction (coal-to-liquids or CTL)[2]
- Oil shale
- Enhanced oil recovery (EOR)

Our objective was to better elucidate the implications of the mitigation programs, e.g., the time required to save and produce significant quantities of liquid fuel, related costs, and economic, fiscal, and jobs impacts. We studied crash program implementation of all options simultaneously because the results provide an upper limit on what might be accomplished under the best of circumstances.[3] No one knows if and when such a program might be undertaken, so our calculations were based on an unspecified starting date, designated as t_0. Although other options are possible, such as biofuels, electric cars, hydrogen cars, fuel switching, and unconventional oil, it is estimated that they would have minimal impacts in the 20-year time horizon, which is the period of the crash activity. These other alternatives, however, could become significant depending on technological advances and possible government actions.

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[1]We term these "physical" mitigation options because they are designed to either save or produce large quantities of liquid fuels and will require massive, continuing capital costs, investments, and consumer expenditures. We distinguish these from more strictly policy-oriented options -- such as the 55 mph speed limit or odd/even gas station days.

[2]The term "coal liquefaction" is used throughout this report to represent the conversion of coal to synthetic hydrocarbon liquids through the gasification and Fischer-Tropsch processes – also known as "indirect coal liquefaction." Coal liquefaction can also describe the process to create a syncrude directly from coal without the intermediate gasification step – direct liquefaction. In this report the terms "coal liquefaction" and "coal-to-liquids (CTL)" are used interchangeably and refer to indirect coal liquefaction – see the discussion in Chapter VI.

[3]The mitigation options covered in the report and the conclusions derived are generalities and simplifications, since the range of mitigation options is not exhaustive and the timing of start-ups is indeterminate. Other savings and substitute liquid fuel sources could be exploited in the U.S. For example, U.S. biomass resources are significant and deserve careful analysis. Commercial ethanol and biodiesel liquid fuels production is already established, and cellulosic ethanol may be capable of producing large quantities of liquid fuels. Analysis of biomass options is especially important because they represent the only renewable energy technology that may be capable of efficiently producing large amounts of substitute liquid fuels for the transportation sector. In addition, there are significant heavy oil resources in several western states and in Alaska that may contribute on a significant scale. Further, there are a number of emerging fuel efficiency options whose implementation could have significant impact, particularly in the long-term.

This study builds on one completed by the authors in 2005 which addressed the issue of world oil peaking.[1] The current study deals exclusively with physical mitigation options for the U.S. The options analyzed in both studies are consistent and are shown in Table EX-1.

Our analysis showed that the mitigation options that we considered can contribute significantly to the saving and production of U.S. liquid fuels, although decades will be needed for significant impact (Figure EX-1) and related costs will be in the trillions of dollars range. The cumulative 20 year impacts of such a massive crash program would be:

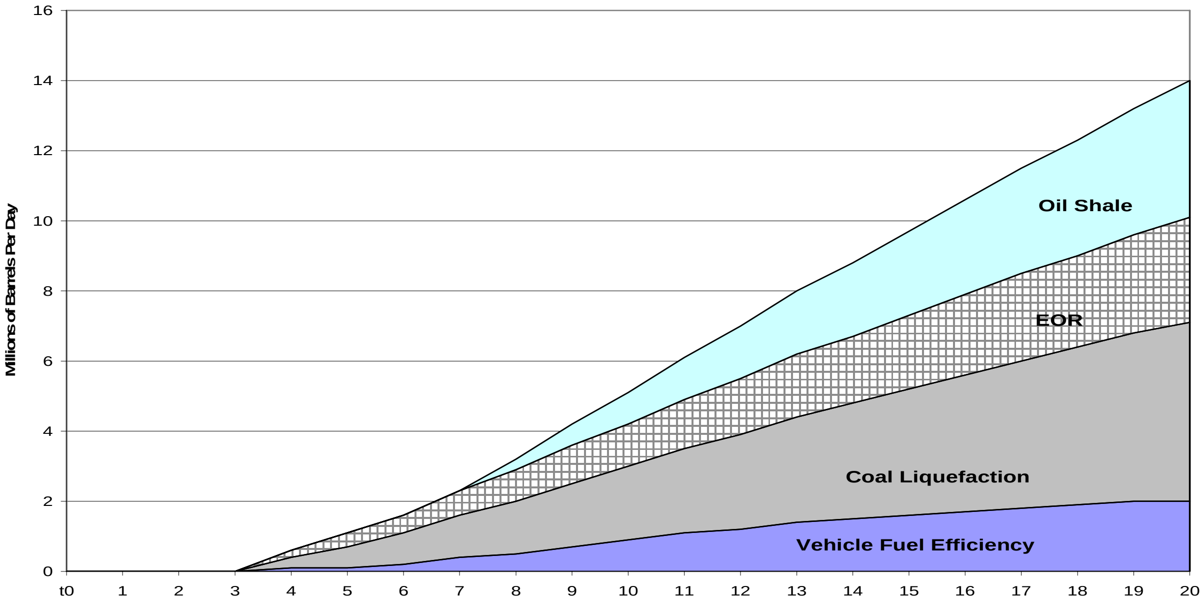
- Savings and production of 44 billion barrels of liquid fuels
- Requirement for over $2.6 trillion of investment
- Over 10 million employment years of jobs created
- Total industry sales of over $3 trillion
- Over $125 billion of industry profits
- Over $500 billion in federal government tax revenues
- Nearly $300 billion in state and local government tax revenues

Table EX-1[2]
Implementation Assumptions

Mitigation Technology	Assumption for the World in the Previous Study	Assumptions for the U.S. in This Study
Vehicle fuel efficiency	Ramping up to a 50% increase in vehicle fuel efficiency after 8 years	Ramping up to a 50% increase in vehicle fuel efficiency after 8 years
Coal-to-liquids	5 new 100,000 bpd plants/yr. 4 years to build	3 new 100,000 bpd plants/yr. 4 years to build
Enhanced oil recovery	World oil production increased by 3 MM bpd after 10 years	175,000 bpd added each year after 4 years preparation
Oil sands/heavy oil	2.5 MM bpd of incremental production achieved 13 years from a decision to accelerate	None
Gas-to-liquids	1 MM bpd achieved in 5 years	None
Oil shale	None	3 new 100,000 bpd plants/yr. 8 year delay

[1]Robert L. Hirsch, Roger H. Bezdek, and Robert M. Wendling, *Peaking of World Oil Production: Impacts, Mitigation and Risk Management*, U.S. Department of Energy, National Energy Technology Laboratory, February 2005.
[2]Oil sands and heavy oil were not included as options because they do not represent substantial U.S. domestic resources.

Figure EX-1
Total Liquid Fuel Impacts

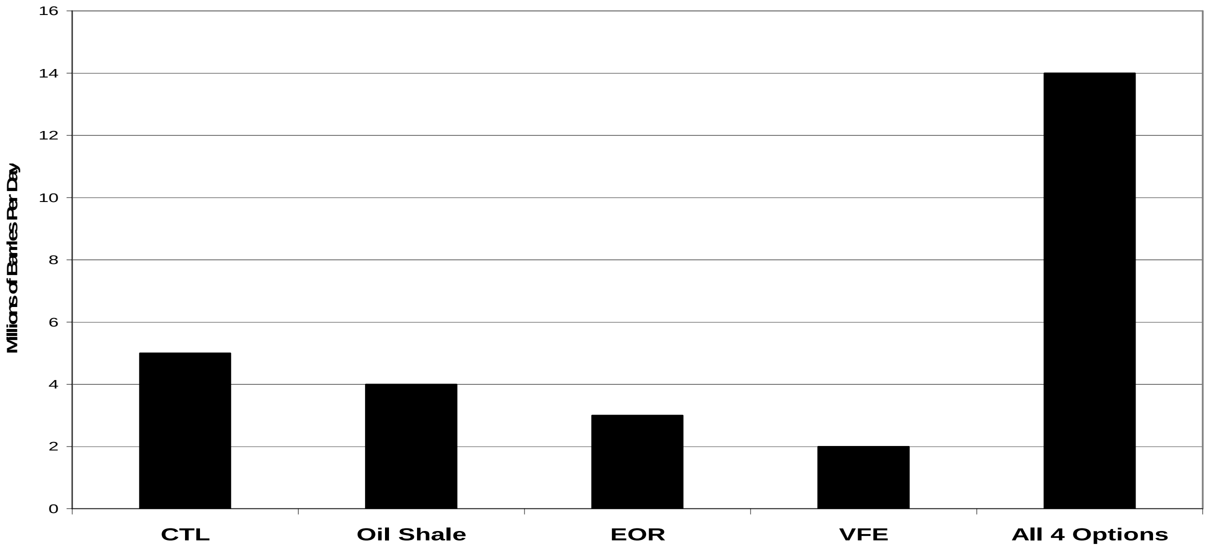


These estimates should be considered as minimum, "best case" estimates, because the final numbers may turn out to be much higher. For example, the $2.6 trillion investment figure does not include cost escalations during the early years of such a program. Related costs could easily double. Further, as all four options are initiated simultaneously, inflationary pressures in specific industries and labor markets could increase costs considerably.

The mitigation options considered herein would have widely differing annual impacts, as illustrated in Figure EX-2 for year t_0+20**.** Impacts will increase continuously over the 20-year scenario period. Relatively small fuel savings and production, sales, jobs, profits, and tax revenues will be generated in the early years, and the impacts will increase every year through year t_0+20. For all of the mitigation options combined, the maximum annual impacts occur in t_0+20.[1]

[1]All of the options considered will continue to have large impacts beyond year t_0+20. In addition, some options not specifically considered here could have significant impacts largely beyond the 20-year horizon – such as fuel cell and hydrogen applications.

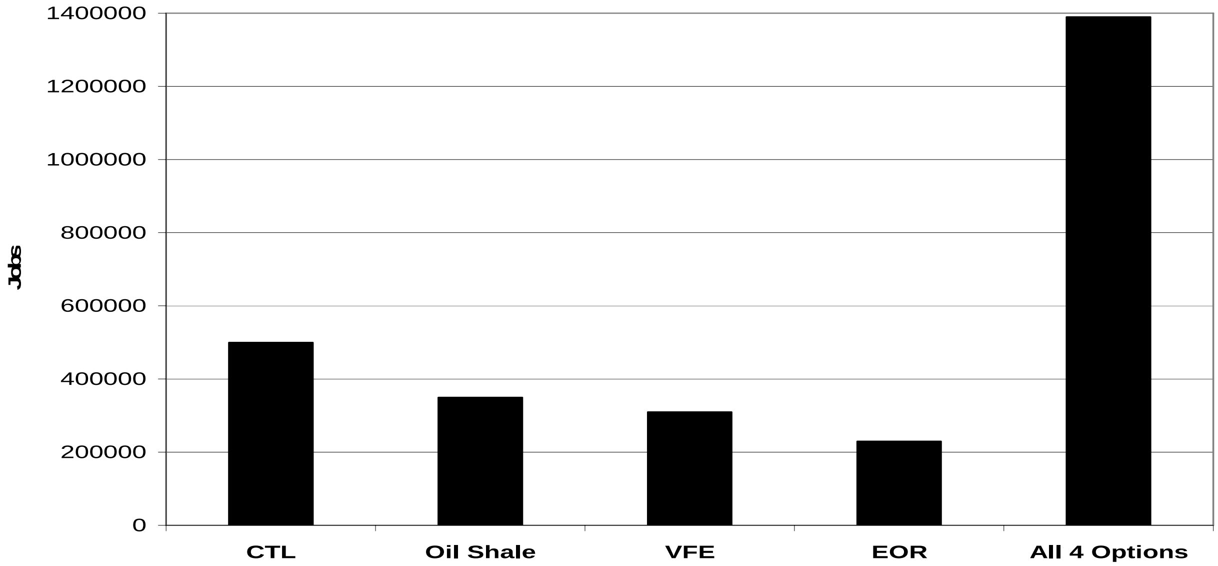
Figure EX-2
Liquid Fuels Saved and Produced in Year t_0+20



In terms of employment, jobs are created throughout the period, but the character and timing of those jobs are very much a function of time. For example, design and construction of substitute fuels plants requires related personnel until a plant is completed, but since new plants are being continuously started, the requirements for these jobs and skills will be continuous over the period. However, operations and maintenance (O&M) employment begins only after substitute fuel plants are completed and come into operation, but as more plants begin to operate related O&M employment increases continually. Thus, in the early years of the mitigation programs, most of the jobs created will be in the design and construction industries and related occupations, but, over time, more and more jobs will be created in operations, maintenance, support, and related fields. The total number of jobs will increase over the 20 years, and the maximum number of jobs will be created in year t_0+20**.** As illustrated in Figure EX-3, in that year:

- CTL creates the most jobs – about 500,000
- Oil shale creates 350,000 jobs
- VFE creates 310,000 jobs
- EOR creates the least number of jobs – about 230,000
- In total, the four options create 1.4 million jobs

Figure EX-3
Jobs Created in Year t_0+20

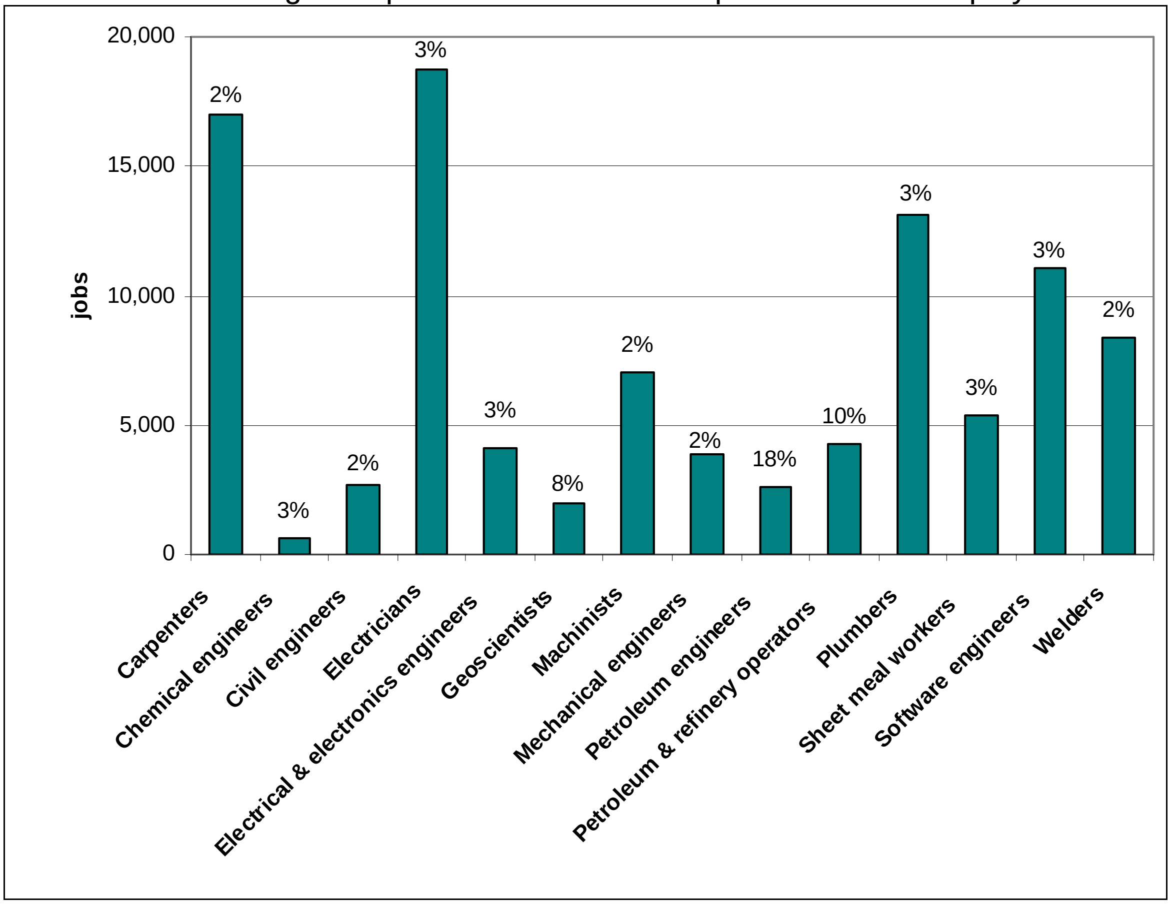


We disaggregated the employment generated by mitigation option into occupations and skills, as illustrated in EX-4 for selected occupations in year t_0+20. The jobs generated are concentrated in fields related to the construction, energy, and industrial sectors, reflecting the requirements of the mitigation options and their supporting industries. Thus, disproportionately large numbers of jobs will be generated for professional, technical, and skilled occupations such as civil engineers, electricians, geoscientists, machinists, mechanical engineers, petroleum system and refinery operators, plumbers, and software engineers. These requirements could cause labor shortages in some industries and professional and skilled occupations, such as chemical, mechanical, electronics, petroleum, and industrial engineers; electricians; sheet metal workers; geoscientists; computer software engineers; skilled refinery personnel; tool and die makers; computer controlled machine tool operators; industrial machinery mechanics, plumbers and pipefitters; oil and gas field technicians, machinists, engineering managers, electronics technicians, carpenters; and others.

The economic activity stimulated and the jobs created will generate substantial tax revenues for the federal, state, and local governments. In year t_0+20:

- CTL will generate $30 billion in tax revenues
- Oil Shale will generate $23 billion in tax revenues
- VFE will generate $22 billion in tax revenues
- EOR will generate $18 billion in tax revenues
- The four mitigation options combined will generate $93 billion in tax revenues

Figure EX-4
Selected Occupational Requirements for the Four Mitigation Options in Year t_0+20
Percentages Represent Demands Compared to 2004 Employment



The scale of United States oil consumption is enormous and making massive changes quickly will require a gigantic, expensive crash program effort and at least two decades. Fortunately, the U.S. is endowed with needed geological resources, capital, labor, and management to undertake such an effort. Further, there are very significant economic benefits that will result from the mitigation programs. For example, in year t_0+20 the combined mitigation options considered in this study will generate:

- Investments of $175 billion
- A total fuel savings and production contribution of 14 MM bpd
- 1.4 million jobs
- $315 billion in industry sales
- $15 billion in industry profits
- $60 billion in federal government tax revenues
- $30 billion in state and local government tax revenues

Future impacts will depend critically on the date that such a national effort is initiated. For example, if the efforts described herein were initiated in 2006, the cumulative U.S. impact in 2026 would be roughly 14 million barrels per day, as illustrated in Figure EX-5. If program initiation was delayed a decade to 2016, the 2026 impact would be only about 5 million barrels per day (Figure EX-6).

Figure EX-5. Mitigation Impacts if Initiated in 2006

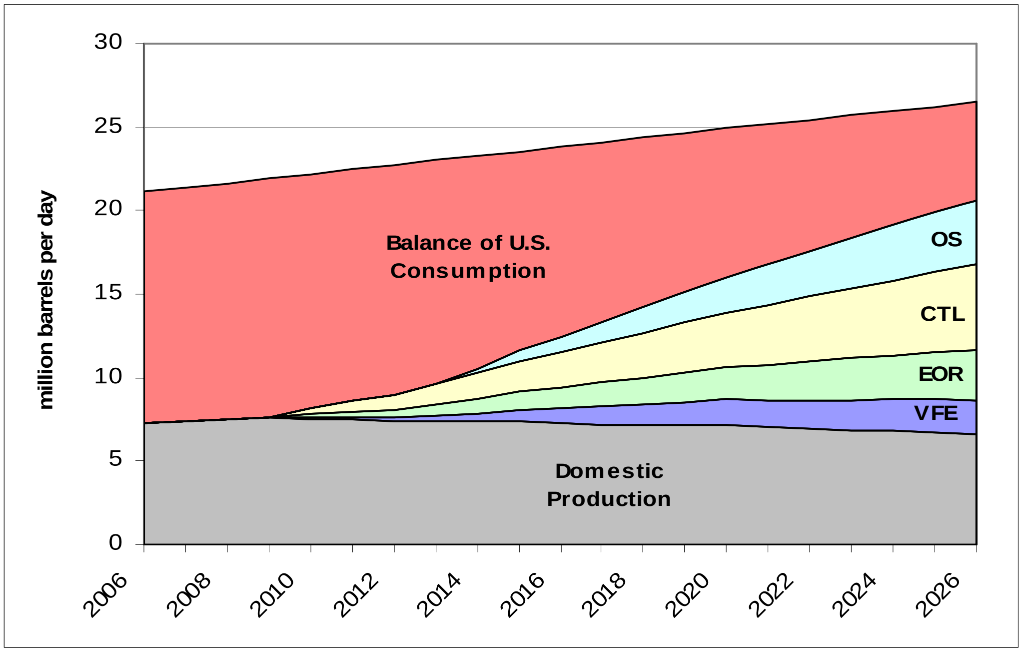
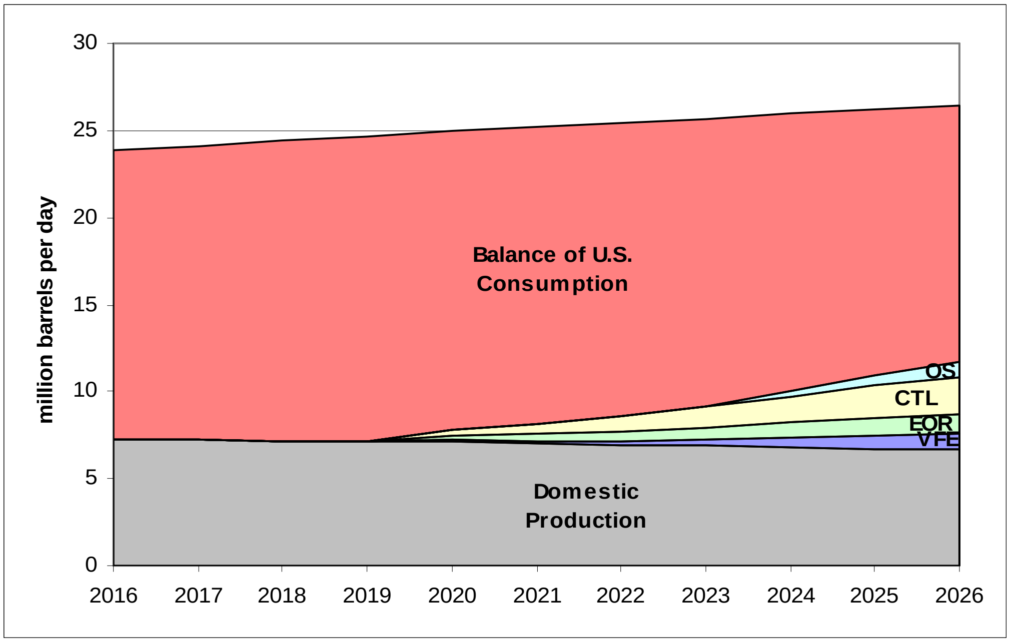
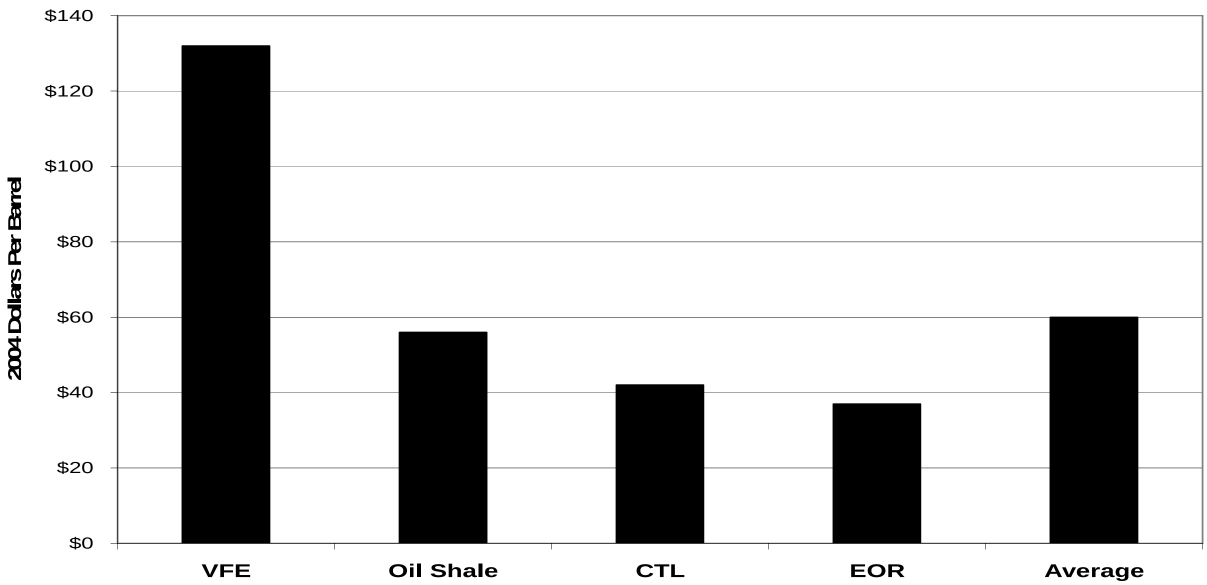


Figure EX-6. Mitigation Impacts if Initiated in 2016



Cumulatively, over the entire 20-year period through year t_0+20, the average cost of a barrel of fuel saved or produced for all of the options is about $60.[1] However, the cost effectiveness of each option differs considerably, as illustrated in Figure EX-7. As illustrated, contrary to conventional wisdom and to some published studies, transportation efficiency may not be the most effective mitigation option.[2] However, the cost estimates for the supply options – especially oil shale and CTL – are subject to a high degree of uncertainty, whereas the cost estimates for the VFE option are likely more accurate. In addition, our analysis at year t_0+20 was truncated, and higher efficiency vehicles will continue to save liquid fuels throughout their life of another 15 years or more. Further, we did not assume further vehicle fuel efficiency improvements after year t_0+8, which may be a limiting assumption.[3]

Figure EX-7
Relative Costs of the Mitigation Options



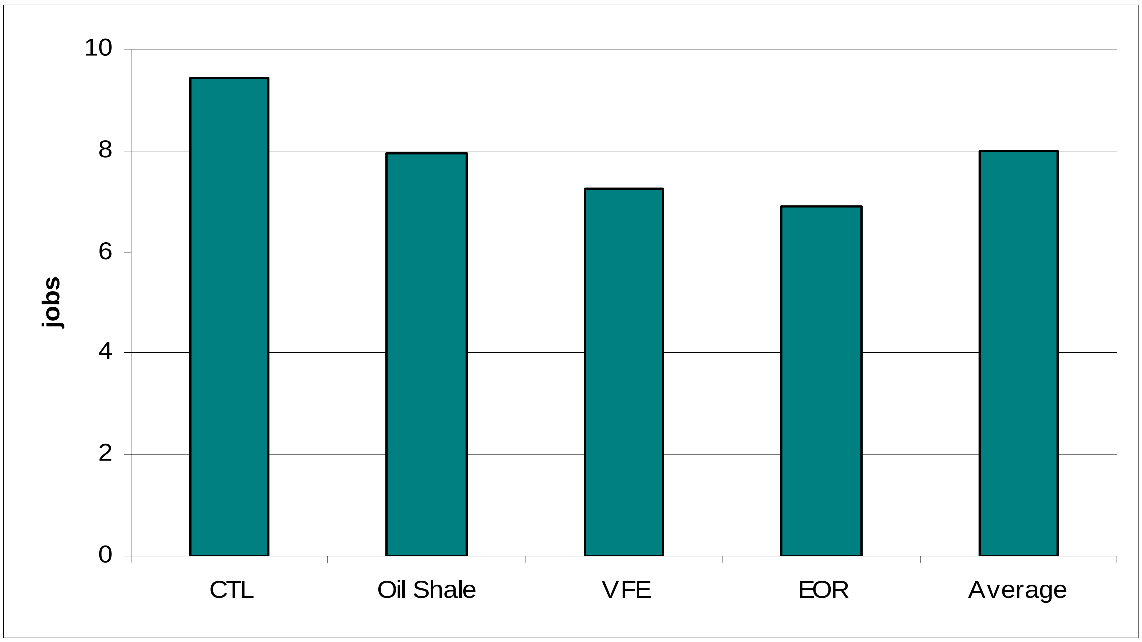
[1]The total estimated costs of the mitigation options over the 20 year period divided by the total estimated liquid fuel savings over the period.

[2]See, for example, National Research Council, National Academy of Sciences. *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*. Washington, D.C.: National Academy Press, 2002; John DeCicco, Feng An, and Marc Ross, *Technical Options for Improving the Fuel Economy of U.S. Cars and Light Trucks by 2010-2015*, American Council for an Energy Efficient Economy, July 2001; Union of Concerned Scientists, *Drilling in Detroit: Tapping Automaker Ingenuity to Build Safe and Efficient Automobiles*, UCS Publications, Cambridge, MA, June 2001.

[3]The impact of further fuel efficiency improvements after year t_0+8 could be significant. For example, if the average mileage efficiency of all autos and trucks continued to improve by one percent per year after year t_0+8, by year t_0+20 the U.S. would be saving an additional half million barrels per day. Further, government subsidies such as income tax credits for hybrid electric vehicles are significantly lowering the consumer cost for investment per barrel saved while, on the other hand, oil shale, CTL, and EOR produce a fungible product that must compete in the world oil market.

Mitigation options can be evaluated on the basis of various criteria. As illustrated in Figure EX-8, in terms of jobs created per dollar of direct investment, the impacts of the mitigation options differ relatively little: The average is about eight jobs per $1 million invested, with CTL creating the most jobs per dollar of expenditure and EOR the least.

Figure EX-8
Total Employment Impact per $1 Million of Direct Costs



In his 2006 State of the Union Address, President Bush stated that the U.S. is "addicted to oil," and he articulated a goal of reducing U.S. oil imports from the Middle East by 75 percent by 2025. While we did not specifically address the question of Middle Eastern oil imports, in terms of reducing total U.S. oil imports we found that, if the mitigation crash programs were to be initiated in 2006, it may be possible to begin to noticeably reduce U.S. oil imports by 2010.[1] In fact, the mitigation options studied in this report may eventually reduce the total level of U.S. imports from the current 13 MM bpd to:

- 11 MM bpd in 2016
- 5 MM bpd in 2026

However, these relatively optimistic findings depend critically upon the crash mitigation option programs being started in 2006. If they are delayed, the oil import gap may not be closed for nearly two decades. For example, if crash program implementation is delayed ten years, until 2016, then by 2026, these mitigation options may contribute about 5 MM bpd but imports would still rise to about 15 MM bpd.

[1]Based on the EIA forecasts of future U.S. oil demands.

If the U.S. becomes seriously motivated to decrease its dependence on oil imports, then multiple paths will be required, even paths beyond those considered in this study. The purpose of this study was to assess what would be required in what we defined as the best, limiting case of physical mitigation. Using the information generated in the previous study and herein, people will hopefully be able to make more informed decisions, should they decide to embark on massive physical mitigation.[1]

It is important to note that initiation of all of the options simultaneously does not even satisfy half of the U.S. liquid fuels requirements prior to 2025. If the peaking of world conventional oil production occurs before 2025, the U.S. may not have a choice in terms of a massive national physical mitigation program. Even with the most optimistic assumptions and assuming crash program implementation, physical mitigation will require decades and trillions of dollars of investment to make substantial contributions.

The results pertaining to the impact on the U.S. economy and employment are particularly interesting. Large investments and efforts need to be undertaken to produce domestic replacements for imported oil, and mitigation initiatives to lower demand for imports, involving massive spending, will lead to large numbers of domestic U.S. jobs and large profits for the producers. Given the inevitable necessity of mitigating the conventional oil shortage, the creation of new employment opportunities in technical and manufacturing areas is a key finding resulting from the analysis. This move of “manufacturing” into the United States instead of importing a non-manufactured “mined” imported hydrocarbon will result in many new jobs and other positive consequences. Such a transition also leverages U.S. natural resources and will substantially improve the U.S. balance of payments.

[1]The information in this report could also be useful for other purposes, such as planning, study, financing, supportive legislation, investment, and construction as well as physical mitigation.

I. INTRODUCTION

I.A. Purpose of the Study

The purpose of this study was to analyze the economic and related aspects of a crash program aimed at the rapid reduction of U.S. dependence on imported oil. This study builds on a recent report that involved analysis of the mitigation of the peaking of world oil production.[1] The approach here involves the use of econometric input-output models to estimate the costs, jobs, taxes, and other parameters representative of such a U.S. crash program.[2]

After providing relevant background, we describe the modeling approach and develop estimates for those physical mitigation technologies[3] that could be deployed within the U.S. based on known resources and capabilities. We then summarize our findings and provide related perspective.

I.B. Background – Highlights of the Previous Study[4]

The peaking of world oil production presents the U.S. and the world with an unprecedented problem. As peaking is approached, liquid fuel prices will increase dramatically, and, without timely mitigation, the economic, social, and political costs will be unprecedented. Viable mitigation options exist on both the supply and demand sides, but to have substantial impact and to avoid severe economic disruptions, they must be initiated more than a decade in advance of peaking.

In 2003, the world consumed just under 80 million barrels per day (MM bpd) of oil. U.S. consumption was almost 20 MM bpd, two-thirds of which was in the transportation sector. The U.S. had a fleet of about 210 million automobiles and light trucks (vans, pick-ups, and SUVs). Under normal conditions, replacement of only half the automobile fleet requires roughly 15 years, and replacement of one-half of the stock of light trucks also requires roughly 15 years. While significant improvements in fuel efficiency are possible in automobiles and light trucks, any affordable approach to upgrading will be inherently time-consuming, because of the lead time to modify production lines, the low fractional replacement rate of vehicles, and the long life of existing vehicles.

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[1]Robert L. Hirsch, Roger H. Bezdek, and Robert M. Wendling, *Peaking of World Oil Production: Impacts, Mitigation and Risk Management*, U.S. Department of Energy, National Energy Technology Laboratory, February 2005.
[2]The estimated costs, jobs, taxes, etc. derived here are representative of the same programs even if they were not "crash," although the magnitude and distribution of these impact over time would differ.
[3]We term these "physical" mitigation options because they are designed to either save or produce large quantities of liquid fuels and will require massive, continuing capital costs, investments, and consumer expenditures. We distinguish these from more strictly policy-oriented options -- such as the 55 mph speed limit or car-pooling mandates.
[4]Robert L. Hirsch, Roger H. Bezdek, and Robert M. Wendling, op. cit.

Besides further oil exploration, which is likely to find ever-diminishing amounts of new oil worldwide, there are commercial options for increasing world oil supply and for the production of substitute liquid fuels worldwide:

1) Improved Oil Recovery (IOR) can marginally increase production from existing reservoirs; one of the largest of the IOR opportunities is Enhanced Oil Recovery (EOR), which can help moderate oil production declines from reservoirs that are past their peak production.

2) Coal liquefaction is a well-established technique for producing clean substitute fuels from the world's abundant coal reserves.

3) Heavy oil/oil sands represent a large resource of lower grade oils, now primarily produced in Canada and Venezuela. Those resources are capable of significant production increases.

4) Clean substitute fuels can be produced from remotely located natural gas, but exploitation must compete with the world's growing demand for liquefied natural gas.

5) Biofuels and related options. Biomass can be grown, collected and converted to substitute liquid fuels by a number of processes. Biomass-to-ethanol is currently produced on a large scale to provide a gasoline additive. The market for ethanol derived from biomass is influenced by federal requirements and facilitated by generous federal and state tax subsidies. Research holds promise of more economical ethanol production from cellulosic ("woody") biomass, but related processes are far from economic, and there are currently no developed biomass-to-fuels technologies that are cost competitive.

Dealing with world oil production peaking will be extremely complex, involve literally trillions of dollars, and require many years of intense effort. To explore these complexities, three alternative mitigation scenarios were analyzed:

- Scenario I assumed that action is not initiated until peaking occurs.
- Scenario II assumed that action is initiated 10 years before peaking.
- Scenario III assumed action is initiated 20 years before peaking.

Possible contributions from each mitigation option were developed, based on an assumed crash program rate of implementation. The approach was simplified in order to provide transparency and promote understanding. Estimates were approximate, but the mitigation envelope that resulted was believed to be directionally indicative of the realities of such an enormous undertaking. The inescapable conclusion was that more than a decade will be required for the collective contributions to produce results that significantly impact world supply and demand for liquid fuels.

Important observations and conclusions from the earlier study were as follows:

1. When world oil peaking will occur is not known with certainty. A fundamental problem in predicting oil peaking is the poor quality and possible political biases in world oil reserves data. Some experts believe peaking may occur soon. The previous study determined that "soon" is within 20 years.

2. The problems associated with world oil production peaking will not be temporary, and past "energy crisis" experience will provide relatively little guidance. The challenge of oil peaking deserves immediate, serious attention, if risks are to be fully understood and mitigation begun on a timely basis.

3. Oil peaking will create a severe liquid fuels problem for the transportation sector, not an "energy crisis" in the usual sense that term has been used.

4. Peaking will result in dramatically higher oil prices, which will cause protracted economic hardship in the United States and the world. However, timely, aggressive mitigation initiatives addressing both the supply and the demand sides of the issue are possible.

5. In the developed nations, the problems will be especially serious. In the developing nations, peaking problems have the potential to be much worse.[1]

6. Mitigation will require roughly two decades of intense, expensive effort, because the scale of world liquid fuels mitigation is inherently extremely large.

7. While greater end-use efficiency is essential, increased efficiency alone will be neither sufficient nor timely enough to solve the problem. Production of large amounts of substitute liquid fuels will be required. A number of commercial or near-commercial substitute fuel production technologies are currently available for deployment, so the production of vast amounts of substitute liquid fuels is feasible with existing technology.

8. Intervention by governments will be required, because the economic and social implications of oil peaking would otherwise be chaotic. The experiences of the 1970s and 1980s offer important guides as to government actions that are desirable and those that are undesirable, but the process will not be easy.

[1]Developing countries suffer more than the developed countries from oil price increases because they generally use energy less efficiently and because energy-intensive manufacturing accounts for a larger share of their GDP. On average, developing countries use more than twice as much oil to produce a unit of output as developed countries, and oil intensity is increasing in developing countries as commercial fuels replace traditional fuels and industrialization and urbanization continue. The vulnerability of developing countries is exacerbated by their limited ability to switch to alternative fuels. In addition, an increase in oil import costs also can destabilize trade balances and increase inflation more in developing countries, where financial institutions and monetary authorities are often relatively unsophisticated. This problem is most pronounced for the poorest developing countries. See the discussion in Hirsch, Bezdek, and Wendling, op. cit.

Mitigating the peaking of world conventional oil production presents a classic risk management problem:

- Mitigation initiated earlier than required may turn out to be premature and result in the misallocation of resources and unprofitable investments, if peaking is long delayed.

- If peaking is imminent, failure to initiate timely mitigation could be extremely damaging.

Prudent risk management requires the planning and implementation of mitigation well before peaking. Early mitigation will almost certainly be less expensive than delayed mitigation. A unique aspect of the world oil peaking problem is that its timing is uncertain, because of inadequate and potentially biased reserves data from elsewhere around the world and other reasons.[1]

The previous analysis clearly demonstrated that the key to mitigation of world oil production peaking will be significant increases in transportation fuel efficiency coupled with enhanced oil recovery, and the construction a large number of substitute fuel production facilities. The time required to mitigate world oil production peaking will be measured on a decade time-scale. Related production facility size will be large and capital intensive. How and when governments decide to address these challenges is yet to be determined.

Consideration of existing commercial and near-commercial mitigation technologies showed that a number of technologies are currently ready for immediate and extensive implementation. The analysis was not meant to be limiting, and it is possible that future research will provide additional mitigation options, some possibly superior to those considered.

In summary, the problem of the peaking of world conventional oil production is unlike any yet faced by modern industrial society. The challenges and uncertainties need to be much better understood. Technologies exist to mitigate the problem. Timely, aggressive risk management will be essential.

Assumptions in the previous study that are relevant to this analysis were as follows:

1. The analysis was for the world, not just the U.S.

2. Crash program implementation was assumed because it was and is the limiting case – the fastest likely possible.

[1]There are additional reasons why the timing of oil peaking is uncertain. These include undiscovered oil deposits, lack of interest in further investment by producers, slow investment, environmental/global warming legislation, significantly lower demand growth than predicted, and success in IOR – see the discussion in Appendix E.

3. No date for peaking was assumed, since related uncertainties are so large.

4. Vehicle fuel economy considerations were focused on light duty vehicles – automobiles and light duty trucks. Vehicle fuel efficiency standards was assumed to be increased by 50 percent above the base in eight years, which was believed to "push the envelope" on the fuel efficiency gains possible from current and emerging technologies.

5. For coal liquefaction, the first plants in a worldwide crash program would begin operation four years after a decision to proceed. Plant sizes of 100,000 bpd of finished, refined product were assumed. Five new plants were assumed to be started each year.

6. Enhanced Oil Recovery worldwide would not begin to show massive production enhancement until five years after project initiation, paced primarily by the difficulties of procuring CO_2 in regions of the world with the largest oil fields. World oil production enhancement due to such a crash effort worldwide was assumed to increase world oil production by roughly 3 percent after 10 years.

I.C. Scope Of This Study

Of the options considered in the previous analysis, the United States could aggressively embark on development of the following three:

1. Vehicle fuel efficiency programs
2. Coal liquefaction
3. Enhanced oil recovery

In this study, the shale oil option was added because the U.S. has the largest shale oil reserves in the world, and there is optimism that the in-situ shale oil recovery concepts now under development will be both commercially and economically viable within a relatively few years.

II. ADDITIONAL PERSPECTIVES ON THE PEAKING OF WORLD CONVENTIONAL OIL PRODUCTION

For the last several decades the world has been consuming much more oil than it has been finding. According to the International Energy Agency (IEA): "Worldwide, the rate of reserve additions from discoveries has fallen sharply since the 1960s. In the last decade, discoveries have replaced only half the oil produced. Nowhere has the fall in oil discoveries been more dramatic than in the Middle East, where they plunged from 187 billion barrels in 1963-1972 to 16 billion barrels during the decade ending in 2002."[1]

As already noted, no one knows precisely when peaking will occur because much of the basic data needed for an accurate forecast fall into one or more of the following categories:

1) Proprietary to companies,
2) State secrets in the major oil exporting countries, and/or
3) Politically biased.

However, even large differences in estimated remaining world oil reserves will not significantly change the date of world peaking, when viewed from the perspective of mitigation. According to EIA: "(Our) results (related to oil peaking) are remarkably insensitive to the assumption of alternative resource base estimates. For example, adding 900 Bbbl (billion barrels) – more oil than had been produced at the time the estimates were made – to the mean USGS resource estimate in the two percent growth case only delays the estimated production peak by 10 years. Similarly, subtracting 850 Bbbl in the same scenario accelerates the estimated production peak by only 11 years."[2]

Most serious analysts do not contest that the peaking of world conventional oil production will occur within the relatively near future, which means sometime between now and 2030. The term "near future" applies to this seemingly long time horizon because massive, crash program mitigation worldwide has been shown to require of the order of 20 years if the world is to avoid serious economic damage. Thus, it is clear that the time for decisive action is either near or may have already passed.

A number of forecasters have accepted OPEC reserves estimates at face value in part because there is no independent source of verification. This acceptance is troubling in light of the fact that past history raises significant questions about the validity of OPEC reporting. In the words of the IEA: "What is clear is that revisions in official (Middle East and North Africa [MENA] reserves) data had little to do with actual discovery of new reserves.[3] Total reserves in many MENA countries hardly changed in

[1]International Energy Agency, *World Energy Outlook 2005*, November 2005, page 132.
[2]Wood, J.H., Long, G.R., and Morehouse, D.F., "World Conventional Oil Supply Expected to Peak in 21st Century," *Offshore*, April 2003.
[3]However, while the lack of transparency about OPEC reserves is troubling, the fact that they made no

the 1990s. Official reserves in Kuwait, for example, were unchanged at 96.5 billion barrels (including its share of the Neutral Zone) from 1991 to 2002, even though the country produced more than 8 billion barrels and did not make any important new discoveries during the period. The case of Saudi Arabia is even more striking, with proven reserves estimated at between 258 and 262 billion barrels in the past 15 years, a variation of less than 2 percent (in spite of production of well over 100 billion barrels)."[1]

There may be very little warning of the onset of world oil peaking. A recent analysis identified countries and regions of the world that are well past peak oil production. That real world experience provides insights as to how world oil peaking might evolve.[2] In situations that were not overly influenced by political instability or cartel action, peaking occurred quite suddenly, and it was not obvious even a year prior to the event. For the regions and countries considered, peaks were very sharp and some post-peak production declines were remarkably steep. The peaking of world conventional oil production may or may not follow this previous experience, but it cannot be ignored.

Past forecasts of world oil peaking have dealt primarily with the geological limitations of oil production, because the ultimate limit on how much oil can be produced from an oil field is governed by geological fundamentals. Forecasters have often tacitly assumed that the owners of the remaining world conventional oil endowment will make the appropriate investments to provide the production needed to meet ever-increasing world demand. However, such an assumption may be presumptuous. As oil exporting countries increasingly consider the implications of world oil peaking, they may well decide to conserve their resource for their own future national needs. Indeed, when the rest of the world is dealing with shortages, countries with oil for domestic consumption will enjoy greater economic opportunities than those countries that must deal with world oil supply shortages and extremely high oil prices.[3]

Recently, both the IEA and the EIA modified their long-term energy outlooks based on the possibility of restrained investment on the part of oil exporters. IEA raised its long-term forecast for oil prices by as much as one-third and painted a pessimistic picture of the future economy if global consumption of oil and natural gas is not reduced. In its *World Energy Outlook Through 2030*, the IEA warned that governments in the oil-rich Middle East may constrain energy-production investment in a quest for

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new discoveries does not rule out major additions to reserves through extensions and revisions – which are common in some oil provinces.

[1]International Energy Agency, *World Energy Outlook 2005*, op. cit., p. 125. With respect to Saudi Arabia, see also Matthew Simmons, *Twilight in the Desert*, 2005.

[2]Robert L. Hirsch, "Shaping the Peak of World Oil Production," *World Oil*, Vol. 226, No. 10 (October 2005).

[3]Some large producers may become more conserving out of concern for their own needs, but if only a few do so, the effects on future world reserves will be limited. Further, if a producer observed a major crash program to develop substitute liquid fuels, this could be a significant disincentive for a more conservative production profile.

higher prices.[1] Persian Gulf states are critical to future oil supplies, since the region contains two-thirds of the world's known reserves and is ever more critical as oil fields in the west are depleted.[2]

EIA significantly increased its projection for oil prices 20 years into the future after concluding that Middle East oil-producing countries are spending less than previously expected. "It has to do with a reassessment of the willingness of oil-rich countries to expand their oil-production capacity," according to G. Daniel Butler, an oil analyst with the Energy Information Administration. "We're not as bullish on expansion of production capacity, especially from OPEC members."[3]

Finally, it is worth reiterating that oil peaking represents a liquid fuels problem, not an "energy crisis" in the sense that term has often been used. Motor vehicles, aircraft, trains, and ships simply have no ready alternative to liquid fuels, certainly not for the existing capital stock, which is very long lived. Non-hydrocarbon-based energy sources, such as renewables and nuclear power, produce electricity, not liquid fuels, so their widespread use in transportation is at best a number of decades away. Accordingly, mitigation of declining world conventional oil production must be narrowly focused on the appropriate mitigation options, at least in the near-term.

[1]International Energy Agency, *World Energy Outlook Through 2030*, 2005.
[2]S. Williams and B. Bahree, "Energy Agency Sets Grim Oil Forecast," *Wall Street Journal*, November 8, 2005, p. A2.
[3]J. Blum, "Oil Prices Predicted to Stay High," *Washington Post*, December 13, 2005, Page D2.

III. STUDY ASSUMPTIONS

In establishing our study assumptions, our goal was to make them as simple, transparent, and robust as possible. For instance, the extensive use of future energy supply-demand forecasts was minimized in order to avoid related uncertainties and criticisms. Nevertheless, we recognize that no approach is without its shortcomings, and this study is no exception.

Our assumptions for this study are listed below. Wherever possible, they paralleled those of the previous analysis.[1]

1. No specific date for world oil peaking was assumed, so the analysis was not contingent on that date.

2. No specific date was assumed for the initiation of the programs described herein. That date was left floating.

3. All calculations were based on actual 2004 data, the last full year for which comprehensive data were available at the time of our analysis.

4. The analysis was based on crash program implementation, the maximum rate believed to be humanly possible.

5. Coal processing plants were considered for either 100 percent liquid fuels production or 100 percent electricity, depending on the circumstances and requirements.

6. The U.S. electric power sector and its needs were not addressed, because they represent separable problems and uncertainties that are not easily forecastable.

7. No incremental use of natural gas was assumed, since the U.S. is already faced with a rapidly growing import dependence.

8. A 20 year time horizon after the beginning of crash program implementation was considered.

9. The initiation of new substitute fuel projects was assumed to be constant, e.g. three new CTL plants each year for the 20 year period studied.

10. The delayed wedge approach was adopted for simplicity and consistency with our previous study, which dealt with worldwide mitigation.

11. Capital funding and financing were assumed to be readily available.

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[1]Hirsch, Bezdek, and Wendling, op. cit.

12. All options were assumed to be pursued in parallel.

13. All necessary personnel qualified to perform the tasks required for design, construction, and operation of each facility were assumed to be available.

14. All equipment for the various projects was assumed to be procured in the U.S., meaning that existing factories would have to be appropriately expanded and/or new factories built on an urgent basis to meet requirements.

15. Permitting and site approvals for new plants were assumed to be rapid and not to be a time constraint.

16. Locations of CTL plants were not specified. However, the siting of some plants was assumed to be close to oil fields to facilitate CO_2 delivery for EOR.

17. Costs for nth plants were adopted, so that initial cost spikes associated with rapid scale up were not considered.

Many of these assumptions are clearly optimistic and open to more detailed consideration. Among the most sensitive are the following:

1. The extremely rapid rate of site approvals and permitting.
2. The absence of large cost escalations certain to occur in the early years of a major crash program.
3. Procurement of most materials in the U.S.
4. The overnight availability of qualified personnel.
5. The constant annual rate of new substitute fuel plant initiation assumed throughout the study period.

We well recognize that new options and forces will come into play over time, as the U.S. phases towards a more sustainable long-term energy future. This study does not deal with such matters, as they are uncertain and open to question. Our goal was to generate a series of estimates aimed at scoping the major dimensions of what might be required to decrease U.S. imported oil dependence as rapidly as humanly possible.

IV. ANALYTICAL APPROACH AND DATABASE

IV.A. The Overall Framework for the Study

In order to develop estimates of the economic requirements and impacts of a major national crash program to mitigate U.S. imported oil dependence, it was necessary to adopt reasonable project and process cost estimates, to utilize established cost and other parameters associated with actual or similar activities, and then to utilize such estimates in an established econometric input-output model. This is what was done in these analyses.

In this chapter we describe the approach, database, and models. In the technology-specific chapters, annual estimates are provided for many parameters, but particular emphasis was given to ten year intervals after program initiation, i.e., t_0+ 10 and t_0+ 20, where t_0 is the unspecified year when the overall effort is initiated.

IV.B. The MISI Model

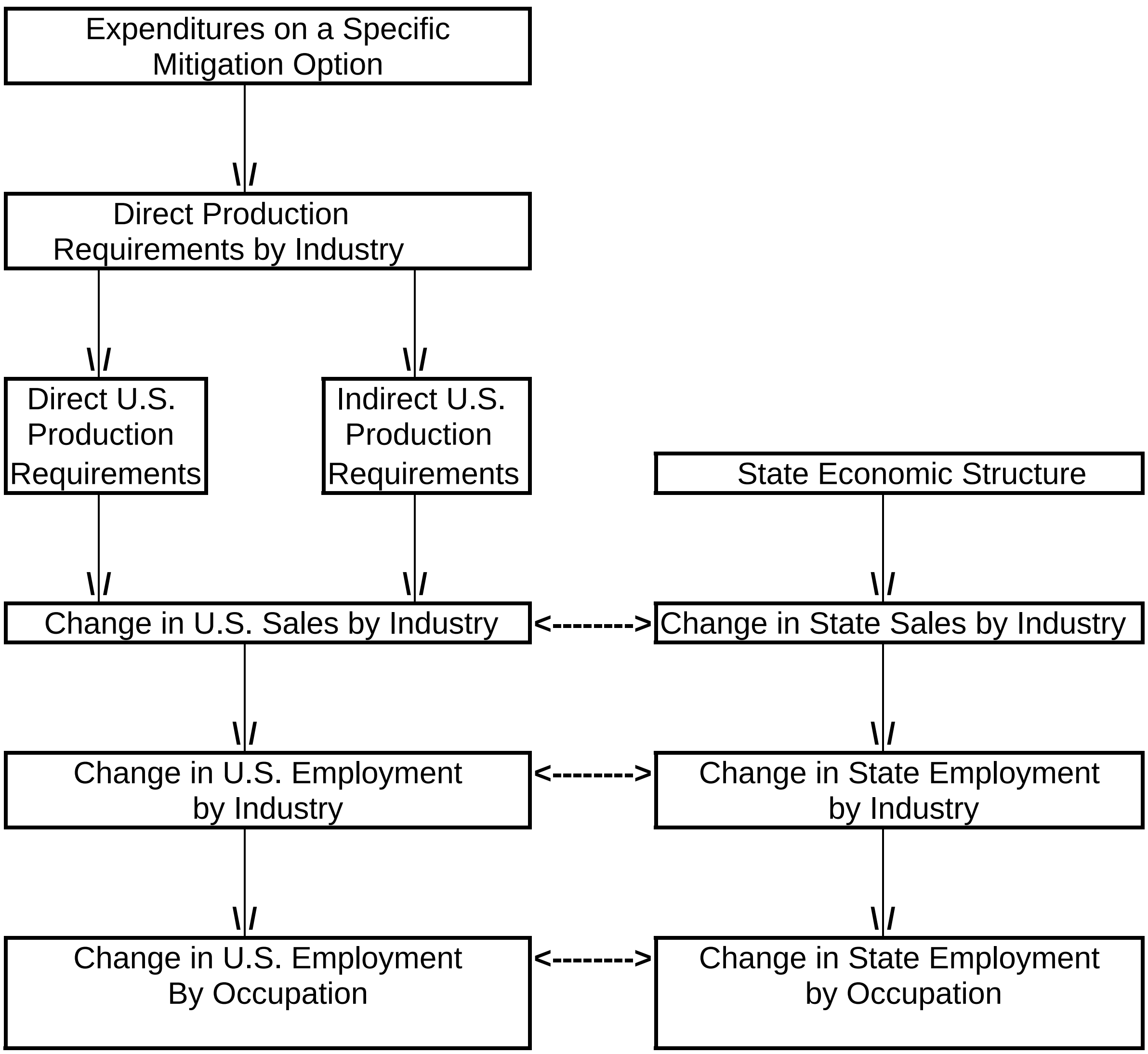
The economic and employment effects of the mitigation options were estimated using the Management Information Services, Inc. (MISI) input-output model and related databases, built upon and derived from a variety of sources, as described below. A simplified depiction of the MISI model as used in this study is shown in Figure IV-1.

The model includes elements from the following sources:

- The U.S. Commerce Department's national input-output model
- A modified version of the Commerce Department's regional econometric forecasting model
- A modified version of the Regional Input-Output Modeling System (RIMS) supplemented with the Census Bureau/BLS industry-occupation matrix -- adapted to state and sub-state economies by MISI

The first step involves estimating the direct requirements for each mitigation option from key supporting industries. For example, construction of a coal liquefaction plant will require hardware and services from one set of suppliers, while vehicle fuel efficiency will generate requirements for hardware and services from a very different set. Construction of a coal liquefaction plant will generate large direct requirements in the construction, mining, coal, chemicals, and related industries, whereas the vehicle fuel efficiency option will generate large direct requirements in such suppliers as motor vehicle parts, plastics and rubber products, primary metals, and fabricated metal products, to name but a few.

Figure IV-1
Use of the MISI Model to Estimate the Economic, Employment, and Occupational Impacts of the Mitigation Options



Expenditures for each mitigation option are translated into per unit output requirements from various suppliers. Key determinants include: 1) the specific option, 2) the specific expenditure/technology configuration selected, 3) the industry requirements structure, and 4) the distribution of expenditures among suppliers.

Direct output requirements for each supplier are estimated, based on our best judgments of the production and technology requirements for the option. Our judgments are often guided by obvious, open literature specifics and sometimes by analogies, e.g., a CTL plant will have similarities with certain chemical plants. These direct requirements dictate how much a supplier must purchase from other industries to produce one unit of output.

Direct requirements give rise to subsequent rounds of indirect requirements. For example, a coal liquefaction plant will require steel, and steel mills require electricity to produce steel. But an electric utility requires turbines to produce electricity, and the turbine factory requires steel from steel mills, while steel mills require electricity, etc.

The sum of the direct plus the indirect requirements represents the total output requirements necessary to produce one unit of output for the mitigation option. Economic input-output (I-O) techniques allow the computation of the direct as well as the indirect production requirements. These total requirements are represented by the "inverse" equations in the model. The ratio of the total requirements to the direct requirements is called the input-output multiplier.

In the next step in the modeling sequence, the direct industry output requirements are converted into total output requirements by means of the input-output inverse equations. These equations provide not only direct requirements, but also second, third, fourth, and nth round indirect industry and service sector requirements.

The total output requirements from each industry are used to compute sales volumes and value added (including profits and taxes) for each industry. Using data on man-hours, labor requirements, and productivity, employment requirements within each supplier industry are estimated, e.g., the total number of jobs created within an industry.

It is next necessary to convert total employment requirements by industry into job requirements for specific occupations and skills. To accomplish this, data on the occupational composition of the labor force within each industry are used to estimate job requirements for 800 occupations within 22 occupational groups encompassing the entire U.S. labor force. This permits estimation of the impact of the mitigation option on jobs for specific occupations and on skills, education, and training requirements.

Overall, this procedure provides an estimate of the effects on employment, personal income, corporate sales and profits, and government tax revenues in the United States and in each state. Estimates can then be developed for detailed industries and occupations.

Industry Profits

The increase in industry sales generated by the various mitigation initiatives will create substantial profits for the industries involved. However, estimating and forecasting profits by industry is difficult for conceptual and definitional reasons and because industry profits differ widely from year-to-year across different sectors and companies. For example, over the past decade profits per dollar of sales varied by a factor of two in the manufacturing sector, by a factor of five in the mining sector, and by a factor of three in the wholesale trade sector. Even for a given year, profits by company vary greatly within sectors. For example, within the manufacturing sector profits in the iron and steel industry, the textile mill products industry, and the rubber and plastics products industry are usually in the range of one to three percent of sales, whereas profits in the electrical and electronic equipment industry, the instruments and related products industry, and the chemical products industry are typically in the range of seven to nine percent of sales. Further, even the profit margins within a specific industry differ markedly -- whereas profits in the chemical products industry are in the range of seven to nine percent of sales, within this industry, profits in the drug industry are usually in the range of 14 - 16 percent of sales, but profits in the industrial chemicals industry are usually in the range of five to seven percent.

Thus, to estimate the profits generated by the increased industry sales resulting from the mitigation initiatives the increased sales in each of the 70 NAICS industries requires applying average profit margins in each industry to the increased sales in that industry. Summation of the profits in all industries yields an estimate of total industry profits generated.

Federal, State, and Local Government Tax Revenues

The increased sales and incomes created by the mitigation options will generate substantial federal, state, and local government tax revenues. Over the past decade, tax revenues for all levels of government have fluctuated between about 29 and 33 percent of income: Federal tax revenues have varied between 19 and 22 percent and combined state and local government taxes (primarily property, income, and sales taxes) have varied between 10 and 11 percent. However, tax revenues as a portion of income differ considerably by state: In some states, such as Connecticut and New York, combined federal-state-local tax revenues total about 33 percent of income, whereas in other states, such as Alabama and South Dakota, combined federal-state-local tax revenues total about 26 percent of income. Accordingly, in estimating the increased tax revenues resulting from the mitigation options we used national averages for both federal and state-local taxes.

Metropolitan Statistical Areas (MSAs)

The final step in the analysis (not carried out in this study) entails assessing the economic impact on specific cities -- Metropolitan Statistical Areas (MSAs). The approach utilized in this work permits disaggregation to the level of most U.S. MSAs and, if desired, to the county level. Empirically, the basis of the sub-state estimates is the MISI version of the Regional Input-Output Modeling System (RIMS II) developed by the U.S. Commerce Department's Bureau of Economic Analysis (BEA).

The MISI model and database permit economic impacts to be estimated for any region composed of one or more counties and for any industry in the national I-O table. MISI can estimate the impacts of project and program expenditures by industry on regional output (gross receipts or sales), earnings (the sum of wages and salaries, proprietors' income, and other labor income, less employer contributions to private pension and welfare funds), and employment.

For the MSAs there may be further interest in estimating the impact on requirements for specific occupations. This can be accomplished using an occupation-by-industry matrix, the coefficients of which show the percent distribution of occupational employment among all industries. A 500-by-700 matrix was developed from the *Current Population Survey* and was modified to conform to the available data.

The methodology employed has been refined and used by MISI for three decades in a variety of studies of energy and environmental projects, economic initiatives, proposed legislation, government programs, etc. A number of these past studies are listed in Appendix A.

IV.C. Databases and Data Sources

In the work reported here, the 70-order industry array shown in Table IV-1 was used.

The databases used in our analysis are derived from a variety of sources including the following:

- The Bureau of Economic Analysis of the U.S. Commerce Department
- The Bureau of the Census of the U.S. Commerce Department
- The Bureau of Labor Statistics of the U.S. Labor Department
- The Energy Information Administration of the U.S. Energy Department
- The U.S. Department of the Treasury

In addition, economic forecasting databases for the U.S. and for most states were utilized. They have been developed and utilized over the past three decades (See Appendix A). Using these databases and related experience, the direct and indirect effects of mitigation options on the national and state economies can be disaggregated into the impacts on:

- Industry sales (490 4-digit NAICS industries)
- Jobs (800 occupations and skills)
- Corporate profits
- Federal, state, and local government tax revenues
- Employment and unemployment (by industry and occupation)
- Net growth or displacement of new businesses
- Major economic, technological, social, and environmental parameters and externalities

Table IV-1
U.S. Input-Output Industry Codes and Titles, 70-Order

National Industry Codes and Titles by NAICS

Industry Code	Industry Title	NAICS Code
111CA	Farms	111,112
113FF	Forestry, fishing, and related activities	113-115
211	Oil and gas extraction	211
212	Mining, except oil and gas	212
213	Support activities for mining	213
22	Utilities	22
23	Construction	23
311FT	Food and beverage and tobacco products	311, 312
313TT	Textile mills and textile product mills	313, 314
315AL	Apparel and leather and allied products	315, 316
321	Wood products	321
322	Paper products	322
323	Printing and related support activities	323
324	Petroleum and coal products	324
325	Chemical products	325
326	Plastics and rubber products	326
327	Nonmetallic mineral products	327
331	Primary metals	331
332	Fabricated metal products	332
333	Machinery	333
334	Computer and electronic products	334
335	Electrical equipment, appliances, and components	335
3361MV	Motor vehicles, bodies and trailers, and parts	3361-3363
3364OT	Other transportation equipment	3364-3369
337	Furniture and related products	337
339	Miscellaneous manufacturing	339
42	Wholesale trade	42
44RT	Retail trade	44, 45
481	Air transportation	481
482	Rail transportation	482
483	Water transportation	483
484	Truck transportation	484
485	Transit and ground passenger transportation	485
486	Pipeline transportation	486
487OS	Other transportation and support activities	487-492
493	Warehousing and storage	493

Table IV-1 (continued)
U.S. Input-Output Industry Codes and Titles, 70-Order

Industry Code	Industry Title	NAICS Code
511	Publishing industries (includes software)	511
512	Motion picture and sound recording industries	512
513	Broadcasting and telecommunications	513
514	Information and data processing services	514
521CI	Federal Reserve banks, credit intermediation, and related activities	521, 522
523	Securities, commodity contracts, and investments	523
524	Insurance carriers and related activities	524
525	Funds, trusts, and other financial vehicles	525
531	Real estate	531
532RL	Rental and leasing services and lessors of intangible assets	532, 533
5411	Legal services	5411
5412OP	Miscellaneous professional, scientific and technical services	5412-5414, 5416-5419
5415	Computer systems design and related services	5415
55	Management of companies and enterprises	55
561	Administrative and support services	561
562	Waste management and remediation services	562
61	Educational services	61
621	Ambulatory health care services	621
622HO	Hospitals and nursing and residential care facilities	622, 623
624	Social assistance	624
711AS	Performing arts, spectator sports, museums, and related activities	711, 712
713	Amusements, gambling, and recreation industries	713
721	Accommodation	721
722	Food services and drinking places	722
81	Other services, except government	81
GFE	Federal government enterprises	n/a
GFG	Federal general government	n/a
GSLE	State and local government enterprises	n/a
GSLG	State and local general government	n/a
S004	Inventory valuation adjustment	n/a

Notes: n/a - Not applicable

Source: Management Information Services, Inc. and U.S. Department of Commerce, Bureau of Economic Analysis, 2006.

V. INCREASES IN VEHICLE FUEL EFFICIENCY STANDARDS

V.A. The Enhanced Vehicle Fuel Efficiency Standards Option

One element of this research involved the estimation of the economic and related impacts of changes in Corporate Average Fuel Economy (CAFE) standards. Below we summarize how our CAFE scenario was derived. Our standards are hypothetical and are not intended to be recommended or preferred fuel economy standards. However, we were careful to ensure that our scenario, while ambitious, was feasible in terms of technology, economics, and timing. These and related policy issues are discussed in some detail in Appendix B.

There exist numerous technologies for increasing vehicle fuel efficiency, which were the starting point for developing the scenario. However, the relationships between increased fuel efficiency and incremental costs are not linear; there are a large number of possible fuel economy increases and resulting cost increases that are possible and a key issue is the level of cost increases that may be justified by the resulting increased vehicle fuel efficiency. While there may be environmental, security, and other reasons for increasing CAFE standards, the tradeoff between improved fuel efficiency and increased vehicle cost is of critical importance. We relied heavily on a landmark National Research Council (NRC) report to develop the ambitious but realistic scenario used here for increasing vehicle fuel efficiency standards[1] (see Appendix B). The NRC addressed this issue by estimating the point at which the incremental costs of new technology begin to exceed the marginal savings in fuel costs, and derived an objective measure of how much fuel economy could be increased while still decreasing consumers' transportation costs.[2] We relied on the NRC's analysis of the estimated incremental fuel efficiency benefits and costs in the construction of our scenario of increased CAFE standards. The scenario "pushes the envelope" on the fuel efficiency gains possible from current or impending technologies and assumes that:

- The fuel efficiency gains possible from incremental technologies identified by the NRC report and other studies are implemented.
- Legislation is enacted in year t_0, and enhanced standards are phased in starting in year t_0 + 3 and attain full implementation in year t_0 + 8.

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[1]National Research Council, National Academy of Sciences. *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*. Washington, D.C.: National Academy Press, 2002. Other recent studies of potential vehicle fuel efficiency improvements include: General Motors Corporation, *Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems -- A North American Study of Energy Use, Greenhouse Gas Emissions and Criteria Pollutant Emissions*," May 2005; Northeast States Center for a Clean Air Future, *Reducing Greenhouse Gas Emissions from Light-Duty Vehicles*, September 2004; Oak Ridge National Laboratory, Energy & Environmental Analysis, Inc., and J.D. Power and Associates, *Future Potential of Hybrid and Diesel Powertrains in the United States Light Duty Vehicle Market*," August 2004; ExxonMobil, "2005 Mid-Term World-Wide Energy Outlook," presentation by Todd Onderdonk, April 12, 2005 at EIA's AEO 2005 conference.

[2]The NRC termed this the cost-efficient level of fuel economy improvement, because it minimizes the sum of vehicle and fuel costs while holding other vehicle attributes constant.

- CAFE standards are increased 50 percent by year $t_0 + 8$.
- The new CAFE standards remain at those levels after year $t_0 + 8$.
- Average vehicle prices increase about $2,700 (12 percent) for the 50 percent increase in mpg by year $t_0 + 8$.

While hypothetical, the scenario is believed to be technologically and economically feasible, and it provides a basis for the estimation of what the likely costs and impacts of attaining these goals might be. It was derived from published engineering studies and data; it assumes that vehicle R&D and technology innovation focus on fuel efficiency rather than on other vehicle characteristics; and it relies on technologies that are either currently available or well along in development. We do not assume radically "new" vehicles or exotic technologies. The timetable involved, a 50 percent increase in mpg and eight years from legislation to full implementation, compares reasonably with the original CAFE timetable that mandated a 53 percent increase (18 mpg to 27.5 mpg) in the years between 1978 and 1985.

However, our hypothesized CAFE increases may also be more challenging than those enacted during the 1970s: The original CAFE enhancements were obtained, in part, by relatively easy weight reductions and by capturing other "low hanging fruit." Future CAFE enhancements will require successful R&D and technological innovation.[1] In addition, our scenario assumes equal percentage fuel economy increases for passenger cars and for light trucks. The NRC and other studies indicate that it may be desirable and more efficient to require larger fuel economy improvements for light trucks than for passenger cars.[2] Thus, the CAFE scenario simulated here may not be the "optimal" scenario. Also, as noted, light trucks are currently exempt from the fuel efficiency standards applicable to passenger vehicles, and requiring both vehicle types to achieve similar fuel efficiency improvements would be a major challenge in and of itself.[3]

Finally, there is no free lunch. Increased CAFE standards, no matter what the potential energy, environmental, economic, and employment impacts, will require that fuel economy enhancement be given priority over other types of vehicle improvements, will increase the purchase price of vehicles, will require manufacturers to produce vehicles that they would not in the absence of the standards, and will require consumers to purchase vehicles that might not exist except for the standards.[4]

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[1]On the other hand, the rapid market penetration of hybrid vehicles may make increased vehicle fuel efficiency easier to attain.

[2]The CAFE standards do not apply to heavy duty trucks, which account for about 16 percent of U.S. petroleum consumption.

[3]It should also be noted that price elasticities for specific vehicles or vehicle types were not estimated. Aside from the practical difficulties of estimating future price elasticities, increasing fuel economy implies trading off other vehicle characteristics, such as horsepower and performance, for increased fuel efficiency. This would change the characteristics of vehicles and would impact sales and price elasticities, especially among different classes of vehicles. Comprehensive analysis of these effects was outside the scope of the work conducted here.

[4]The potential impact of vehicle fuel efficiency standards on vehicle safety is especially contentious. The NRC report concluded that enhanced CAFE standards would increase risk, although several committee

V.B. Estimating the Impact of Enhanced Vehicle Fuel Efficiency Standards

As discussed above, the increased vehicle fuel efficiency (VFE) standards we model here are ambitious, but feasible, and assume that[1]:

- Legislation is enacted in year t_0, and enhanced CAFE standards are phased in starting in year $t_0 + 3$ and attain full implementation in year $t_0 + 8$ -- as shown in Table V-1.
- CAFE standards are increased 50 percent by year $t_0 + 8$: For passenger cars from the 2004 actual 29 mpg for new vehicles to 43.5 mpg and for light trucks from the 2004 actual 21 mpg for new vehicles to 31.5 mpg.[2]

Table V-1
Scenario for Increased Vehicle Fuel Efficiency Standards

Year*	Passenger Cars	Light Trucks
2004	29 mpg**	21 mpg**
$t_0 + 3$	30.5 mpg	22.1 mpg
$t_0 + 4$	31.9 mpg	23.1 mpg
$t_0 + 5$	34.8 mpg	25.2 mpg
$t_0 + 6$	37.7 mpg	27.3 mpg
$t_0 + 7$	40.6 mpg	29.4 mpg
$t_0 + 8$	43.5 mpg	31.5 mpg

*Assuming legislation mandating enhanced standards is enhanced in year t_0.
**Actual 2004 new vehicle mpg as estimated by the U.S. Department of Transportation and Oak Ridge National Laboratory.

The timing and extent of the changes in CAFE standards hypothesized here are roughly comparable to those of the original CAFE standards, but are more ambitious than recommended or proposed changes made in recent years.[3]

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members dissented – see National Research Council, op. cit.

[1]In developing the scenario and analyses we relied on previous MISI work in this area; see Appendix D.

[2]Our percent increases in vehicle fuel efficiencies are derived from the actual 2004 mpg figures (29 mpg for new passenger vehicles and 21 mpg for light trucks), not from the current existing CAFE standards (27.5 mpg for new passenger vehicles and 20.7 mpg for light trucks). It was felt that it was more realistic to base the scenario on actual vehicle fuel efficiencies, although the difference for light truck mpg requirements is minimal. Expressed as a percent of the current CAFE standards, the year $t_0 + 8$ increase in CAFE standards for passenger vehicles is 58 percent and for light trucks is 52 percent.

[3]The original CAFE standards mandated a 53 percent increase in fuel efficiency for passenger vehicles (from 18 mpg to 27.5 mpg) were passed in 1975, began to be implemented in 1978, and achieved full implementation in 1985. The original CAFE standards for light trucks were set at 17.5 mpg in 1982 and were gradually increased to 20.5 mpg by 1987. They were increased to the current level of 20.7 mpg in 1996. In August 2005, the Bush Administration proposed new rules mandating an increase in fuel economy standards for minivans, pickup trucks, and sport utility vehicles starting in 2008 and to be phased in by 2011. In 2002, Senator Ernest Hollings (D-S.C.) proposed raising the CAFE standard 35 percent to 37 mpg by 2014; Senator John McCain (R-Ariz.) proposed raising the CAFE standard 31 percent to 36 mpg by 2016; and the bipartisan proposal by Senator McCain and Senator John Kerry (D-Mass.) proposed raising the CAFE standard 27 percent to 35 mpg by 2015.

As discussed in Chapters III and IV, we used the most recent data available. The U.S. transportation fleet currently contains about 136 million passenger vehicles and about 85 million "light trucks," and in 2004, 7.5 million new passenger vehicles and 9.4 million new light trucks were sold. We assumed that the number of new vehicles sold each year and the proportion of new passenger vehicles and light trucks remains constant.

In year $t_0 + 3$ we assumed that the 7.5 million new passenger vehicle fleet had a five percent increase in fuel efficiency and that the 9.4 million new light truck fleet also had a five percent increase in fuel efficiency – see Tables V-1 and V-2. We then assumed the average miles per year traveled by a passenger vehicle at 12,200 and by a light truck at 11,400.

Table V-2
Percent Increases in Vehicle Fuel Efficiencies in the Scenario

	Percent Increase From 2004 Actual mpg (29 mpg for passenger cars and 21 mpg for light trucks)	
Year*	**Passenger Cars**	**Light Trucks**
$t_0 + 3$	5	5
$t_0 + 4$	10	10
$t_0 + 5$	20	20
$t_0 + 6$	30	30
$t_0 + 7$	40	40
$t_0 + 8$	50	50

*Assuming legislation mandating enhanced standards is enhanced in year t_0.

Next, we estimated the annual gasoline consumption for each class of vehicle based on the actual 2004 fuel economy of new passenger vehicles (29 mpg) and new light trucks (21 mpg). We then estimated the likely gasoline savings by assuming that in year $t_0 + 3$ new passenger vehicles and light trucks would achieve five percent better mpg. These estimated savings were multiplied, respectively, by the number of new passenger vehicles assumed to be sold in that year (7.5 million) and the number of new light trucks assumed to be sold in that year (9.4 million) to estimate total annual gasoline savings.[1] The resulting estimate of gasoline savings was then divided by two, to account for new vehicles being purchased throughout the year. Finally, the gallons of gasoline saved were divided by 42 to estimate barrels of oil saved in that year, yielding an estimated oil savings in year $t_0 + 3$ of approximately 5 million barrels.

In year $t_0 + 4$, the total gasoline savings is the sum of the total savings resulting from the increased fuel efficiency of the new vehicles produced in year $t_0 + 3$ plus the savings resulting from the new vehicles produced in year $t_0 + 4$. In year $t_0 + 4$ we assumed that the 7.5 million new passenger vehicles sold had a 10 percent increase in fuel efficiency (31.9 mpg instead of 29 mpg) and that the 9.4 million new light trucks sold had a 10 percent increase in fuel efficiency (23.1 mpg instead of 21 mpg) – Table

[1]We implicitly assumed that the number of vehicles retired each year equaled the number of new vehicles purchased in that year.

V-1. We again used the previously estimated average miles per year traveled by a passenger vehicle at 12,200 and by a light truck at 11,400.

Next, we used the estimated the annual gasoline consumption for each class of vehicle based on the actual 2004 fuel economy of new passenger vehicles (29 mpg) and new light trucks (21 mpg). We then estimated the likely gasoline savings by assuming that in year t_0 + 4 new passenger vehicles would get 10 percent better mpg and that new light trucks would also get 10 percent better mpg. These estimated savings were multiplied, respectively, by the number of new passenger vehicles assumed to be sold in that year (7.5 million) and the number of new light trucks assumed to be sold in that year (9.4 million) to estimate total annual gasoline savings. The resulting estimate of gasoline savings was then divided by two, to account for new vehicles being purchased throughout the year. Finally, the gallons of gasoline saved were divided by 42 to estimate barrels of oil saved in that year, and the estimated oil savings in year t_0 + 4 is approximately 9 million barrels.

The total savings in year t_0 + 4 is thus 19 million barrels (the total savings in year t_0 + 4 resulting from the new vehicles produced in year t_0 + 3 – which is 10 million barrels) plus 9 million barrels (the total savings resulting from the new vehicles produced in year t_0 +4). This methodology was used to estimate the total cumulative oil savings for all years through t_0 + 20.

Mathematically, the methodology is straightforward. Oil savings in year t_0 + n is equal to sum of the savings in years t_0 + 3, t_0 + 4, t_0 + 5, ….., t_0 + n-1, plus the savings resulting from the new vehicles produced in year t_0 + n divided by two. Savings are relatively small in the first years after the new standards are introduced but grow cumulatively as new more fuel efficient vehicles are produced each year and as newer vehicles come to comprise a larger share of the total existing vehicle stock.[1]

V.C. The Impact of Enhanced Vehicle Fuel Efficiency Standards

V.C.1. Fuel Savings

The annual fuel savings resulting from the enhanced CAFE standards are shown in Table V-3 and Figure V-1. These show that the initial fuel savings in year t_0 + 3 (the year in which the standards begin) are minimal, but increase rapidly thereafter:

- By year t_0 + 10, total annual oil savings are 325 million barrels: 200 million barrels from light trucks and 125 million barrels from passenger vehicles -- about 900,000 bbls/day in oil savings.

[1]Eventually, the new vehicles produced will begin to replace the more fuel efficient vehicles produced in years t_0 + 3 and later, rather than those produced prior to year t_0 + 3, and the rate of increase in gasoline savings will decline – since we assume here that CAFE standards are not increased beyond year t_0 + 8.

- By year t_0 + 20, total annual oil savings are 740 million barrels: 365 million barrels from light trucks and 375 million barrels from passenger vehicles -- just over two million bbls/day in oil savings.

To place these fuel savings in perspective:

- In 2004 the U.S. consumed 20.5 million bbls/day of oil, and the EIA reference case projects that in 2025 the U.S. will consume about 28 millions bbls/day.[1] Thus, the year t_0 + 20 oil savings represents 7 – 10 percent of total U.S. oil consumption.
- In 2004, the U.S. consumed 9.1 million bbls/day of motor gasoline, and the EIA reference case projects that in 2025 the U.S. will consume about 13 million bbls/day.[2] Thus, the year t_0 + 20 fuel savings represent 15 - 22 percent of total gasoline consumption.

Table V-3 and Figure V-1 illustrate that the light truck sector of the market accounts for most of the fuel savings over most of the scenario period. However, by year t_0 + 17 these savings level off and by year t_0 + 20 the fuel savings from both vehicle sectors are about equal – although fuel savings from passenger vehicles continue to increase. The reason is that with a stock of 85 million light trucks, replacing them at a rate of 9 million a year leads to the entire stock being replaced 1.4 times over the 20-year period. After year t_0 + 17, light trucks averaging 31.5 mpg are simply replacing light trucks averaging 31.5 mpg and potential fuel savings are maxed out. However, fuel savings from passenger vehicles continue to increase because the 135 million vehicle stock is being replaced with more efficient vehicles at a rate of 7 million per year. Nevertheless, at around year t_0 + 24 we estimate that the passenger vehicle fuel savings will also begin to level off, since vehicles getting 43.5 mpg will then be replacing 43.5 mpg vehicles.

This has an important policy implication. Here we assumed that the enhanced CAFE standards are phased in by year t_0 + 8 and remain fixed thereafter, which is why the fuel savings from light trucks levels off in year t_0 + 17 and the fuel savings from passenger vehicles levels off in year t_0 + 24. Thus, the incremental fuel savings from enhanced CAFE standards will eventually level off. If additional fuel savings are desired, further voluntary improvements by manufacturers or increases in vehicle fuel efficiency standards will be required beyond year t_0 + 8.[3]

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[1] U.S. Energy Information Administration, *Annual Energy Outlook 2005 With Projections to 2025*, January 2005.

[2] Ibid.

[3] The impact of further fuel efficiency improvements after year t_0+8 could be significant. For example, if the average mileage efficiency of all autos and trucks continued to improve by one percent per year after year t_0+8, by year t_0+20 the U.S. would be saving an additional half million barrels per day.

Table V-3
Annual Oil Savings From Enhanced Vehicle Fuel Efficiency Standards

	Autos	Light Trucks	Total
	(million barrels)		
t_0	0	0	0
1	0	0	0
2	0	0	0
3	2	3	5
4	7	12	19
5	17	27	44
6	32	51	83
7	51	82	133
8	74	120	194
9	100	160	260
10	125	200	325
11	150	240	390
12	175	278	453
13	200	310	510
14	225	335	560
15	250	352	602
16	275	362	638
17	300	365	665
18	325	365	690
19	350	365	715
20	375	365	740

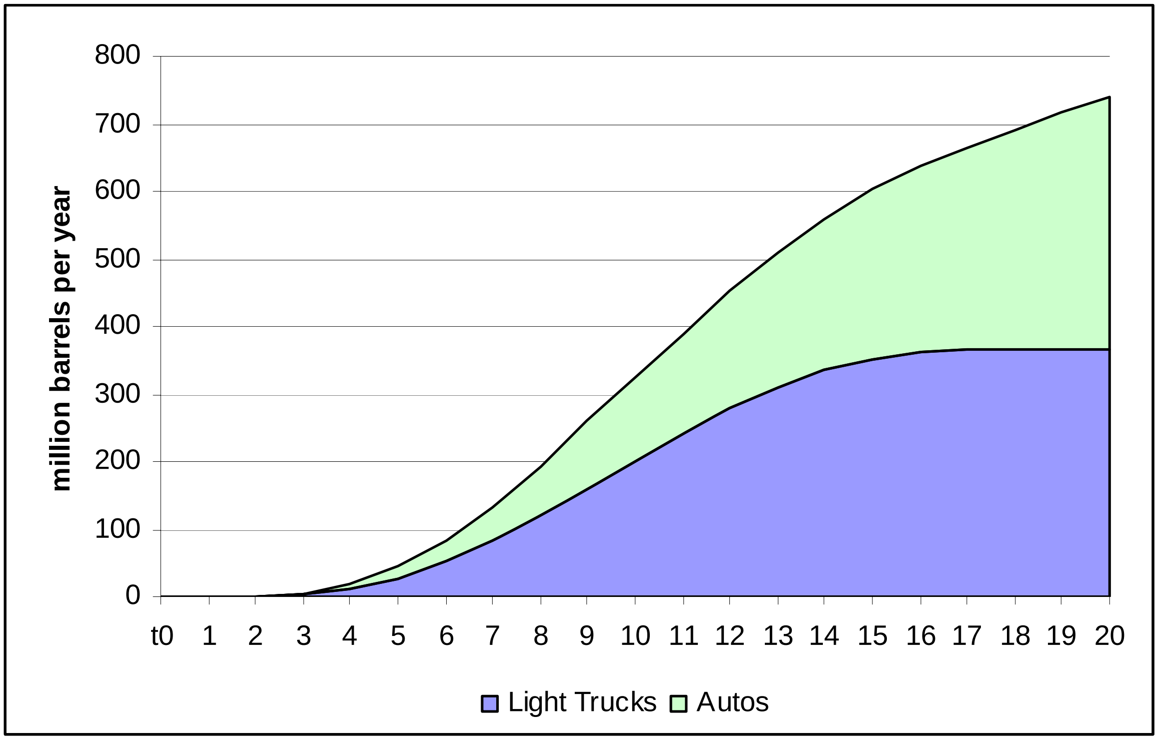
V.C.2. Macroeconomic and Employment Effects

Direct Expenditures in the U.S. Economy

The direct impacts on the economy of enhanced VFE standards and the total impacts (direct plus indirect) were estimated using the following parameters:

- Number of autos affected: 135 million
- Number of light trucks affected: 169 million
- Total vehicles affected over the 20 years: 304 million
- Incremental cost per car: $2,500 (2004 dollars)
- Incremental cost per truck: $3,500 (2004 dollars)
- Total cost to consumers/manufacturers: $927 billion (2004 dollars)

Figure V-1
Annual Oil Savings From Enhanced Vehicle Fuel Efficiency Standards

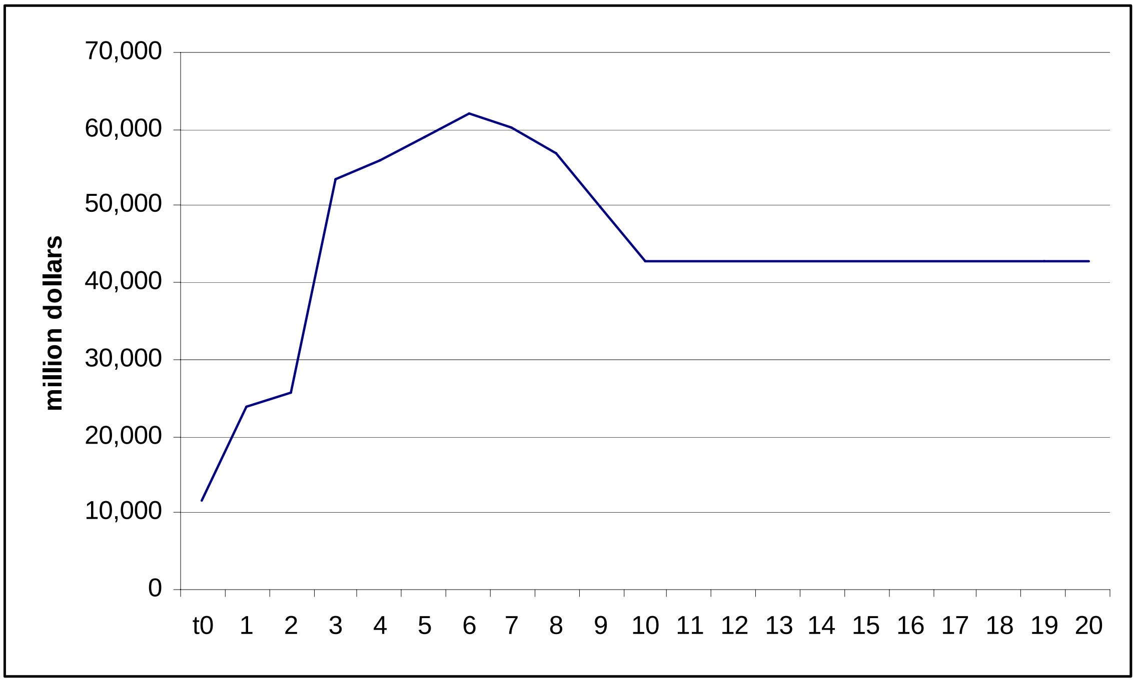


The direct impacts on the economy of enhanced vehicle fuel efficiency standards are illustrated in Figure V-2, which illustrates that the direct expenditures in the economy increase rapidly after year t_0 as manufacturers ramp up design, engineering, and retooling programs to comply with new standards that begin to be phased in at year $t_0 + 3$. They reach a maximum in year $t_0 + 6$ and then decline and level off at year $t_0 + 9$. Maximum expenditures occur in $t_0 + 6$ due to both the investments required by manufacturers and the increased prices of the vehicles that are being paid by vehicle purchasers. After $t_0 + 9$, further investments are not required by manufacturers because by that year the vehicle fuel efficiency standards have be fully implemented, and the only additional direct expenditures are those incurred by consumers paying increased prices for the more fuel efficient vehicles.[1] Specifically:

- In $t_0 + 3$, the incremental direct expenditures in the economy total about $53 billion.
- In $t_0 + 6$, the incremental direct expenditures in the economy total about $62 billion.
- In year $t_0 + 10$, the incremental direct expenditures in the economy total about $43 billion and remain at this level through year $t_0 + 20$.

[1]This is a direct result of our assumption that, after the enhanced vehicle fuel efficiency standards are phased in by year $t_0 + 8$, no further increases in standards are mandated.

Figure V-2
Direct Impacts on the Economy From
Enhanced Vehicle Fuel Efficiency Standards



Impact on Sales, Jobs, and Industries

We estimated the total (direct plus indirect) impacts of enhanced VFE standards and determined that they will likely increase industry sales and employment substantially. As illustrated in Tables V-4 through V-7, enhanced VFE standards will:

- Generate $107 billion in total industry sales in year $t_0 + 6$ and $74 billion in year $t_0 + 20$.
- Generate 500,000 additional jobs in year $t_0 + 6$ and more than 300,000 jobs in year $t_0 + 20$.

While significant, the job estimates must be put into perspective: In 2010, U.S. employment will total 142 million; in 2020 it will total 154 million; in 2030 it will total 166 million. Thus, while there will be job gains and job displacements due to enhanced VFE standards, the net job change is likely to be strongly positive, i.e., increasing CAFE standards will create jobs, not destroy them.[1]

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[1]See the discussion Roger H. Bezdek and Robert M. Wendling, "Fuel Efficiency and the Economy," *American Scientist*, Vol. 93 (March-April 2005), pp. 132-139; Roger H. Bezdek and Robert M. Wendling, "Potential Long-term Impacts of Changes in U.S. Vehicle Fuel Efficiency Standards," *Energy Policy*, Vol. 33, No. 3 (February 2005), pp. 407-419; Management Information Services, Inc. and 20/20 Vision, *Fuel Standards and Jobs: Economic, Employment, Energy, and Environmental Impacts of Increased CAFE Standards Through 2020*, report prepared for the Energy Foundation, San Francisco, California, July 2002.

Table V-4
Top 20 Industries Affected in Year t_0 + 6 by Enhanced Vehicle Fuel Efficiency Standards – Ranked by Sales

Industry	**Sales Increase in Year t_0+6** (billions of 2004 dollars)
1. Motor vehicles, bodies and trailers, and parts	$25.4
2. Wholesale trade	8.4
3. Primary metals	8.3
4. Fabricated metal products	7.0
5. Miscellaneous professional, scientific and technical services	6.4
6. Computer and electronic products	4.0
7. Plastics and rubber products	3.8
8. Other services, except government	3.6
9. Machinery	3.5
10. Chemical products	3.4
11. Management of companies and enterprises	2.9
12 Truck transportation	2.5
13. Federal Reserve banks, credit intermediation, and related activities	2.0
14. Broadcasting and telecommunications	2.0
15. Real estate	1.7
16. Administrative and support services	1.6
17. Textile mills and textile product mills	1.2
18. Insurance carriers and related activities	1.1
19. Oil and gas extraction	1.1
20. Rental and leasing services and leasers of intangible assets	1.0
All other industries	16.5
Total, all industries	$107

As discussed in Chapter IV, we estimated the impacts of increased VFE standards on economic output and employment within the 70 two- and three-digit NAICS code industries. In general, in terms of industry sales and jobs we found that throughout the forecast period, the motor vehicle and related industries would benefit considerably. For example, in terms of total industry sales, as shown in Tables V-4 and V-6:

- In year t_0 + 6, sales in the motor vehicles industry increase by $25 billion and in year t_0 + 20 sales increase by $27 billion.
- In year t_0 + 6, sales in the primary metals industry increase by $8 billion and in year t_0 + 20 sales increase by $4 billion.
- In year t_0 + 6, sales in the miscellaneous professional, scientific, and technical services industry increase by $6.4 billion and in year t_0 + 20 sales in this industry increase by $3.2 billion.
- In year t_0 + 6, sales in the computer and electronics product industry increase by $4 billion and in year t_0 + 20 sales in this industry increase by $2.5 billion.
- In year t_0 + 6, plastics and rubber products industry sales increase by $3.8 billion; in year t_0 + 20 sales increase by $2.3 billion.

Table V-5
Top 20 Industries Affected in Year t_0 + 6 by Enhanced Vehicle Fuel Efficiency Standards – Ranked by Employment

Industry	Job Increases in Year t_0+6 (thousands of jobs)
1. Motor vehicles, bodies and trailers, and parts	56
2. Other services, except government	48
3. Wholesale trade	47
4. Fabricated metal products	38
5. Miscellaneous professional, scientific and technical services	33
6. Administrative and support services	28
7. Primary metals	24
8. Truck transportation	19
9. Machinery	15
10. Plastics and rubber products	14
11. Management of companies and enterprises	13
12. Retail trade	12
13. Computer and electronic products	11
14. Federal Reserve banks, credit intermediation, and related activities	9
15. Food services and drinking places	7
16. State and local government enterprises	7
17. Warehousing and storage	7
18. Other transportation and support activities	6
19. Textile mills and textile product mills	6
20. Chemical products	6
All other industries	92
Total, all industries	498

The motor vehicles industry is the only industry where the total sales increase is larger in year t_0 + 20 than in year t_0 + 6 -- $27 billion as compared to $25 billion. This is because by year t_0 + 20 there is very little design and engineering work required to adhere to the enhanced VFE standards, and most of the increased industry sales derive from consumers purchases of more fuel efficient vehicles.

As shown in Tables V-5 and V-7, relative increases in industry employment in each year track increases in industry sales, although there are some differences due to the different productivity and output/employment relationships among industries. With respect to the job increases in different industries:

- In year t_0 + 6, 56,000 jobs are created in the motor vehicles industry and in year t_0 + 20 58,000 jobs are created in this industry.
- In year t_0 + 6, 47,000 jobs are created in wholesale trade and in year t_0 + 20 28,000 jobs are created in this industry.
- In year t_0 + 6, 48,000 jobs are created in services (except government) and in year t_0 + 20 24,000 jobs are created.

Table V-6
Top 20 Industries Affected in Year t_0 + 20 by Enhanced Vehicle Fuel Efficiency Standards – Ranked by Sales

Industry	Sales Increase in Year t_0+20 (billions of 2004 dollars)
1. Motor vehicles, bodies and trailers, and parts	$26.7
2. Wholesale trade	4.9
3. Primary metals	4.4
4. Fabricated metal products	4.2
5. Miscellaneous professional, scientific and technical services	3.2
6. Computer and electronic products	2.5
7. Plastics and rubber products	2.3
8. Machinery	2.2
9. Chemical products	2.1
10. Other services, except government	1.8
11. Management of companies and enterprises	1.6
12. Truck transportation	1.4
13. Federal Reserve banks, credit intermediation, & related activities	1.2
14. Broadcasting and telecommunications	1.1
15. Real estate	1.0
16. Administrative and support services	0.9
17. Textile mills and textile product mills	0.8
18. Insurance carriers and related activities	0.7
19. Electrical equipment, appliances, and components	0.6
20. Oil and gas extraction	0.6
All other industries	9.6
Total, all industries	$73.9

- In year t_0 + 6, 38,000 jobs are created in the fabricated metal products industry and in year t_0 + 20, 23,000 jobs are created.
- In year t_0 + 6, 33,000 jobs are created in miscellaneous professional, scientific, and technical services, and in year t_0 + 20, 17,000 jobs are created in this industry.

As noted, "Motor vehicles, bodies and trailers, and parts" is the only industry in which sales and employment increase more in year t_0 + 20 than in t_0 + 6. Further, in year t_0 + 20 this industry accounts for a much larger portion of the increase in sales and jobs than in year t_0 + 20. Specifically, in this industry:

- In year t_0 + 6, increased sales of $25 billion represent 24 percent of total increased sales of $107 billion.
- In year t_0 + 20, increased sales of $27 billion represent 36 percent of total increased sales of $74 billion
- In year t_0 + 6, increased employment of 56,000 represents 11 percent of the total 500,000 jobs created.
- In year t_0 + 20, increased employment of 58,000 represents 19 percent of the total 311,000 jobs created.

Table V-7
Top 20 Industries Affected in Year t_0 + 20 by Enhanced Vehicle Fuel Efficiency Standards – Ranked by Employment

Industry	**Job Increases in Year t_0+20** (thousands of jobs)
1. Motor vehicles, bodies and trailers, and parts	58
2. Wholesale trade	28
3. Other services, except government	24
4. Fabricated metal products	23
5. Miscellaneous professional, scientific and technical services	17
6. Administrative and support services	16
7. Primary metals	13
8. Truck transportation	11
9. Machinery	9
10. Plastics and rubber products	9
11. Management of companies and enterprises	8
12. Retail trade	7
13. Computer and electronic products	7
14. Federal Reserve banks, credit intermediation, & related activities	5
15. Food services and drinking places	4
16. State and local government enterprises	4
17. Warehousing and storage	4
18. Textile mills and textile product mills	4
19. Other transportation and support activities	4
20. Chemical products	3
All other industries	109
Total, all industries	311

In sum, the bottom line is that the VFE mitigation option modeled here will save substantial quantities of liquid fuels, will generate large requirements for the products and services of many industries, and will create substantial numbers of jobs:

- In year t_0+6, the VFE option results in the savings of about 225,000 barrels of liquid fuels, generates over $100 billion in industry sales, and creates 500,000 jobs.
- In year t_0+20, the VFE option results in the saving of over 2 million barrels of liquid fuels, generates about $75 billion in industry sales, and creates over 300,000 jobs.

V.C.3. Industry Profits

The increase in industry sales generated by the VFE mitigation initiative will create substantial profits for the industries. To estimate the profits generated by the increased industry sales resulting from the VFE initiative, the increased sales in each of the 70 NAICS industries have to be estimated by applying the profit margins in each industry to the increased sales in that industry. Summation of the profits in all related industries yields an estimate of total industry profits generated.

Applying the estimates of profit margins by detailed industry to the increased sales in each industry indicates that:

- In year t_0+6, the VFE option results in increased industry profits of approximately $4.3 billion.
- In year t_0+20, the VFE option results in increased industry profits of approximately $3.1 billion

V.C.4. Federal, State, and Local Government Tax Revenues

The increased sales and incomes created by the VFE mitigation option will generate substantial federal, state, and local government tax revenues; specifically:

- In year t_0+6, the VFE option generates approximately $32 billion in increased tax revenues: $21 billion in federal tax revenues and $11 billion in state and local tax revenues.
- In year t_0+20, the VFE option generates approximately $22 billion in increased tax revenues: $15 billion in federal tax revenues and $7 billion in state and local tax revenues.

V.D. Summary of Major VFE Impacts

The VFE mitigation option modeled here will save substantial quantities of liquid fuels, will generate large requirements for the products and services of many industries, will create substantial numbers of jobs, and will generate significant federal, state, and local government tax revenues. The major impacts of the VFE option can be summarized as follows:

In year t_0+6[1], the VFE option:

- Results in savings of 225,000 barrels of liquid fuels
- Generates $100 billion in industry sales
- Creates over $4 billion in industry profits
- Generates $21 billion in federal tax revenues
- Generates $11 billion in state and local tax revenues.
- Creates 500,000 jobs

In year t_0+20, the VFE option:

- Results in savings of over 2 million barrels of liquid fuels
- Generates $75 billion in industry sales
- Creates over $3 billion in industry profits
- Generates $15 billion in federal tax revenues

[1]In VFE we focus on year 6 rather than year 10, because year 6 is the one with the maximum economic impact.

- Generates $7 billion in state and local tax revenues.
- Creates over 300,000 jobs

V.E. Occupational Impacts

We disaggregated the employment generated by the VFE mitigation option into occupations and skills, as illustrated in Table V-8 for selected occupations in years t_0+6 and t_0+20.[1] The jobs generated are disproportionately concentrated in fields related to the automotive, energy, and industrial sectors, reflecting the requirements of the VFE mitigation option and its supporting industries. Thus, disproportionately large numbers of jobs will be generated for various professional, technical, and skilled occupations such as:

- Automotive mechanics and technicians
- Computer-controlled machine tool operators
- Cutting and press machine operators
- Electrical and electronics engineers
- First line production supervisors
- Industrial engineers
- Industrial machinery mechanics
- Industrial production managers
- Machinists
- Mechanical engineers
- Software engineers
- Tool and die makers
- Welders

It is important to note that the jobs generated by the VFE mitigation option will be widely distributed among all occupations and skill levels and, while the numbers of jobs created in different occupations differ substantially, employment in virtually all occupations will be generated. The vast majority of the jobs created by the VFE initiative will be standard jobs created, directly and indirectly, for accountants, engineers, bookkeepers, computer analysts, clerks, factory workers, security guards, truck drivers, technicians, sales representatives, analysts, mechanics, etc. and most of the persons employed in these jobs may not even realize that they owe their livelihood to the mitigation options.

[1]Employment was disaggregated among more than 700 individual occupations.

Table V-8
Occupational Impacts of the Vehicle Fuel Efficiency Option
(Selected Occupations)

Occupation	Jobs in Year t_0+6	Jobs in Year t_0+20
Accountants and auditors	5,800	3,500
Automotive mechanics and technicians	3,700	2,000
Bookkeeping and accounting clerks	9,200	5,500
Cashiers	4,900	2,800
Computer-controlled machine tool operators	1,600	1,200
Computer programmers	2,500	1,500
Computer support specialists	2,700	1,600
Computer systems analysts	2,500	1,500
Cutting and press machine operators	3,100	2,100
Electrical and electronics engineers	1,200	800
Electronic equipment assemblers	2,700	2,000
Financial managers	2,800	1,700
First line production supervisors	7,700	3,900
Industrial engineers	1,900	1,400
Industrial machinery mechanics	2,400	1,700
Industrial production managers	1,800	1,300
Inspectors and testers	5,400	3,800
Janitor and cleaners	6,600	3,900
Machinists	4,300	3,000
Management analysts	1,900	1,100
Mechanical engineers	2,100	1,400
Production assistants	5,200	3,700
Purchasing agents	1,700	1,200
Security guards	3,000	1,700
Shipping and receiving clerks	5,200	3,400
Software engineers	3,000	1,800
Team assemblers	13,900	9,900
Tool and die makers	1,300	900
Truck Drivers	10,900	6,700
Welders	3,700	2,600
Total, all occupations	498,000	311,000

VI. COAL LIQUEFACTION

VI.A. The U.S. Coal Resource Base

U.S. coal resources are immense: It is often stated that the U.S. is the "Saudi Arabia of Coal" and has 250 years of coal reserves available.[1] The U.S. currently has over one-quarter of the world's recoverable coal, more than Russia and over twice that of China. This compares to the U.S.'s oil reserves that are two percent of the world's total and natural gas that are three percent. Current Department of Energy coal resource estimates are given in Table VI-1, which indicates that U.S. recoverable coal has the energy content equivalent of about one trillion barrels of oil.

Table VI-1
U.S. Coal Reserves and Oil Equivalent

	Coal Resources	Oil Equivalent*
Recoverable reserves	275.1 billion tons	550 billion bbls
Demonstrated reserve base** (2003)	497.7 billion tons	995 billion bbls
Identified resources***	1.7 trillion tons	3.4 trillion bbls
Total resources (identified and undiscovered)	3.96 trillion tons	7.9 trillion bbls

*Estimated at 2 bbls net oil production per ton of coal input in a coal-to-liquids operation. Current U.S. coal production is slightly more than one billion tons per year. A portion of U.S. reserves will be needed to satisfy traditional coal markets.
**Portion of known coal reserves that could be profitably mined and marketed.
***Coal for which estimates have been computed to a high, moderate, or low degree of geologic assurance.

Source: Southern States Energy Board, *American Energy Security: Building a Bridge to Energy Independence and a Sustainable Energy Future*, Norcross, Georgia, 2005.

These estimates have not been updated since the 1970s, and a reassessment could reveal an even greater coal resource base. In any case, DOE's estimated reserve base of 497.7 billion "Demonstrated" tons is a good preliminary estimate for available U.S. coal reserves that will ultimately be recovered. This category includes all coal seams at least 28 inches thick in the measured and indicated categories. While not all of this coal is mineable, there are other resources that are mineable but are not included, including 4 trillion tons not yet well enough explored to properly assess.[2]

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[1]U.S. Energy Information Administration, *U.S. Coal Reserves: 1997 Update*, February 1999; Management Information Services, Inc., *Coal: A Secure U.S. Energy Source*, prepared for the National Coal Council, 2002.

[2]Several caveats are in order. The Demonstrated Reserve Base may be overstated due to a number of factors, such as the inclusion of unmineable coal, failure to account for quality differences between coals, lack of consistency between state and federal agencies' estimation techniques, etc. At least as important, many laws, regulations, and policies at all levels of government prevent effective recovery of available coal reserves. These can prevent coal from being mined economically and can limit the amount of coal available and, in addition, some regulations limit exploration for coal. There are thus vast areas of the U.S. containing large coal reserves where, at present, coal production is severely limited or prohibited. This implies that it may difficult to rapidly increase coal production in the near future if required for coal liquefaction. These limitations are not widely known and their potential implications are not understood..

Coal can be delivered by rail, barge, or truck to almost any location in the U.S. Coal's high energy density, its ability to be easily transported and easily stored as a solid without deteriorating, its widespread abundance, and its low cost per energy-unit (Btu) to produce and transport make it an important primary feedstock for producing liquid fuels. While there are substantial coal reserves in 38 states,[1] production will come primarily from existing production regions such as the Powder River Basin, the Rocky Mountains, the Illinois Basin, Central Appalachia, Northern Appalachia, the Great Plains, and Texas. U.S. coal reserves that are now reserved for the production of electricity could provide feedstock for large-scale liquid fuel production, if electricity was produced by other means.[2]

VI.B. The Coal Liquefaction Concept

There are two basic technologies for producing liquid fuels from coal: Direct and indirect liquefaction:[3]

- Direct liquefaction reacts coal with H_2, sometimes in the presence of a liquid solvent, and aggressive reaction conditions are required (temperatures > 400ºC, pressures > 100 atmospheres, and sometimes an appropriate catalyst). A synthetic crude is created that must then be refined to produce gasoline and diesel fuel.
- Indirect liquefaction involves gasification of coal to produce a syngas mixture of CO and H_2. The syngas is then converted into clean liquid fuels via Fischer-Tropsch (F-T) synthesis.

In this analysis we assume that all of the coal-to-liquid (CTL) plants to be built will utilize indirect liquefaction.[4] Indirect coal liquefaction can produce high quality liquid fuels that can supplement or substitute for the fuels now produced from petroleum.[5] In our analysis we used assumptions analogous to a baseline IGCC power plant, where oxygen-blown coal gasification is used to produce synthesis gas.

Our model CTL plants produce either 100 percent liquid fuels or 100 percent electric power needed for in-situ shale oil production, described in a late chapter. Modern gasification technologies have been dramatically improved over the years, with the result that over 200 gasifiers are in commercial operation around the world, a number operating on coal.[6] Gas cleanup technologies are well developed and utilized in refineries worldwide. F-T synthesis is also well developed and commercially

[1]National Mining Association, "U.S. Coal Reserves by State and Type – 2003," October 2004.
[2]National Research Council, *Fuels to Drive Our Future*, National Academies Press, 1990.
[3]Richard A. Bajura and Edwar M. Eyring, "Coal and Liquid Fuels," presented at the GCEP Advanced Coal Workshop, Provo, Utah, March 2003.
[4]At present, there is no commercial CTL plant using direct liquefaction technology.
[5]See the discussion in Eric D. Larson and Ren Tingjin, "Synthetic Fuel Production by Indirect Coal Liquefaction," *Energy For Sustainable Development*, Vol. VII, No. 4 (December 2003), pp. 79 – 102; and David Gray and Glen Tomlinson, "Efficient and Environmentally Sound Use of Our Domestic Coal and Natural Gas Resources," *Energeia*, Vol. 8, No. 4 (1997), pp. 1-6.
[6]*Coal Gasification 2005: Roadmap to Commercialization*, www.researchandmarkets.com/reports.

practiced on a large scale. Importantly, coal liquids from gasification/F-T synthesis are of such high quality that they do not need to be refined. When co-producing electricity, coal liquefaction is estimated to be capable of providing clean substitute fuels at $35-45 per barrel.[1]

VI.C. Coal Liquefaction Plants

A number of coal liquefaction plants were built and operated in Germany during World War II, and the Sasol Company in South Africa subsequently built a number of larger, more modern gasification-based facilities.[2] At present, Sasol is the world's major commercial user of CTL technology and has produced synfuels and chemical feedstock from coal for over a half-century. The company currently has a capacity equivalent to about 150,000 bbls/day – capable of meeting about 40 percent of South Africa's oil requirements.[3]

While the first two Sasol CTL plants were built under normal business conditions, the Sasol Three facility was designed and constructed on a crash basis in response to the 1979 Iranian revolution. The project was completed in just over three years after the decision to proceed. Sasol Three was essentially a duplicate of Sasol Two on the same site using a large cadre of experienced personnel. Sasol Three was brought "up to speed almost immediately."[4]

The Sasol Three example represents the lower bound on what might be accomplished in a twenty-first century crash program to build coal liquefaction plants. This is because the South African government made a quick decision to replicate an existing plant on an existing, coal mine-mouth site without the delays associated with site selection, environmental reviews, public comment periods, etc. In addition, engineering and construction personnel were readily available, and there were a number of manufacturers capable of providing the required heavy process vessels, pumps, and other auxiliary equipment.

There has been a recent resurgence in interest CTL in the U.S.,[5] Australia, and China; for example:

- In 2004, Chinese companies signed separate agreements with Sasol and Shell to study the feasibility of building CTL plants.

[1]David Gray, "Producing Liquid Fuels From Coal," presentation at the National Academy of Sciences Systems Workshop on Trends in Oil Supply and Demand, Washington, D.C., October 20-21, 2005; David Gray, et. al. "*Coproduction of Ultra Clean Transportation Fuels, Hydrogen, and Electric Power from Coal"*. Mitretek Systems Technical Report MTR 2001-43, July 2001.
[2]*P du P Kruger, "*Startup Experience at Sasol's Two and Three," Sasol, 1983.
[3]"Sasol: Reaching New Frontiers," Sasol Fuels International, February 2005; Ken Silverstein, "Coal Liquefaction Plants Spark Hope,' *The Power Report*, November 1, 2004.
[4]Collings, J. *"Mind Over Matter – The Sasol Story: A Half-Century of Technological Innovation,"* Sasol. 2002.
[5]DOE is supporting a small CTL facility in Gilberton, Pennsylvania to convert coal waste into synthetic fuels. The plant will produce 5,000 bpd of clean synthetic fuel using coal waste and will cost about $600 million.

Sasol is planning to build two CTL plants in China with anticipated start-up in 2010/2011 and joint production of some 160,000 bpd of oil.[1]

- A Foster Wheeler and Huanqiu joint venture was awarded a feasibility study contract by Sasol and the Combined Chinese Working Team, which is expected to be completed by January 2006.[2]
- Headwaters, Inc. is developing CTL projects in Arizona and North Dakota. It is the principal developer of two separate indirect coal liquefaction plants that are intended to produce 10,000 bpd of liquid fuels, as well as electricity. Plant expansions could increase output up to 50,000 bpd of liquid fuel production.[3]
- Houston-based DKRW Energy is planning an integrated power and CTL facility in Wyoming that is targeted to come online between 2008 and 2010. The facility resembles an advanced IGCC plant creating synthesis gas, which would be partly used to produce 33,000 bpd of synthetic diesel and naphtha.[4]
- A CTL project is planned to be demonstrated in Australia to integrate Syntroleum's air-based F-T technology with Linc Energy's underground coal gasification (UCG) technology, and coal will be converted *in-situ* to a syngas that can be used in power generation or in an F-T process.[5] The first commercial phase of the Chinchilla Project involves installation of a 30-40 MW power plant and over the next several years a 17,000 bpd Syntroleum CTL plant and power plant expansion.[6]

VI.D. Specifications for New Coal Liquefaction Plants

Our CTL scenario involves a crash program of plant construction beginning in year t_0. The basic assumptions for the CTL scenario were based on recent work by David Gray:[7]

- The technology used is indirect liquefaction.
- Each plant is sized to produce 100,000 bpd of liquid fuels.
- Liquid fuels production consists of gasoline and mid-distillates – other products of the plants were not included in our estimates.
- Each plant requires four years from decision-to-build to first production of product.

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[1]Presentation by Rudi Heydenrich at the Howard Well Energy Conference, April 2005. (www.sasol.com).
[2]"CTL Boom in Sight?" *AMFI Newsletter*, August 2005.
[3]"Headwaters in MOUs to Develop Two Major Coal-to-Liquids Projects," *CTL News*, August 9, 2005.
[4]"DKRW to Acquire Coal Resources for Coal-to-Liquids Facility," *CTL News*, March 10, 2005.
[5]UCG has been used in the Former Soviet Union for 40 years.
[6]"Underground Coal-Gasification, Coal-to-Liquids Fuel Project in Australia," *CTL News*, August 15, 2005.
[7]The economic parameters represent an average of the costs for utilizing bituminous and sub-bituminous coal. See David Gray, "Producing Liquid Fuels From Coal," op. cit.

- The construction cost of each plant is $7 billion (2004 dollars).[1]
- The O&M costs for each plant total $350 million (2004 dollars) per year.
- The costs of the coal feedstock for each plant total $260 million (2004 dollars) per year.
- Three new CTL plans are committed each year for the period of the study, with the first set of plants coming on-line in year t_0+4.[2]
- Construction will begin on three new plants per year.
- The plants are not geographically specified, e.g. they are generic plants that could be sited anywhere in the U.S.
- The costs specified do not include those of transportation or other infrastructure.[3]
- In some cases, CO_2 from these plants will be used for EOR as discussed later. In other cases, CO_2 is assumed to be released to the atmosphere.
- Plant costs are distributed equally over the construction period.

VI.E. Direct Costs and Impacts of the CTL Plants

The direct costs and impacts resulting from the CTL scenario are summarized in Figures VI-1 and VI-2. Figure VI-1 shows the direct costs incurred in plant construction and operations over the 20-year period and illustrates that:

- All of the costs incurred initially are construction costs, and these increase rapidly beginning in year t_0.
- No O&M costs are incurred until year t_0+4, when the first set of plants begins operation.
- More than $50 billion in construction costs will be expended by the time the first three plants begin production of liquid fuels.
- After year t_0+4, construction costs remain constant at $21 billion per year, since three new plants are being started each year.
- After year t_0+4, O&M costs rise rapidly as three new plants come on-line each year.
- After year t_0+15, annual O&M costs exceed construction costs by an increasingly large margin each year as more plants are brought on-line.
- Cumulative construction and O&M costs over the 20-year period total approximately $700 billion (2004 dollars).

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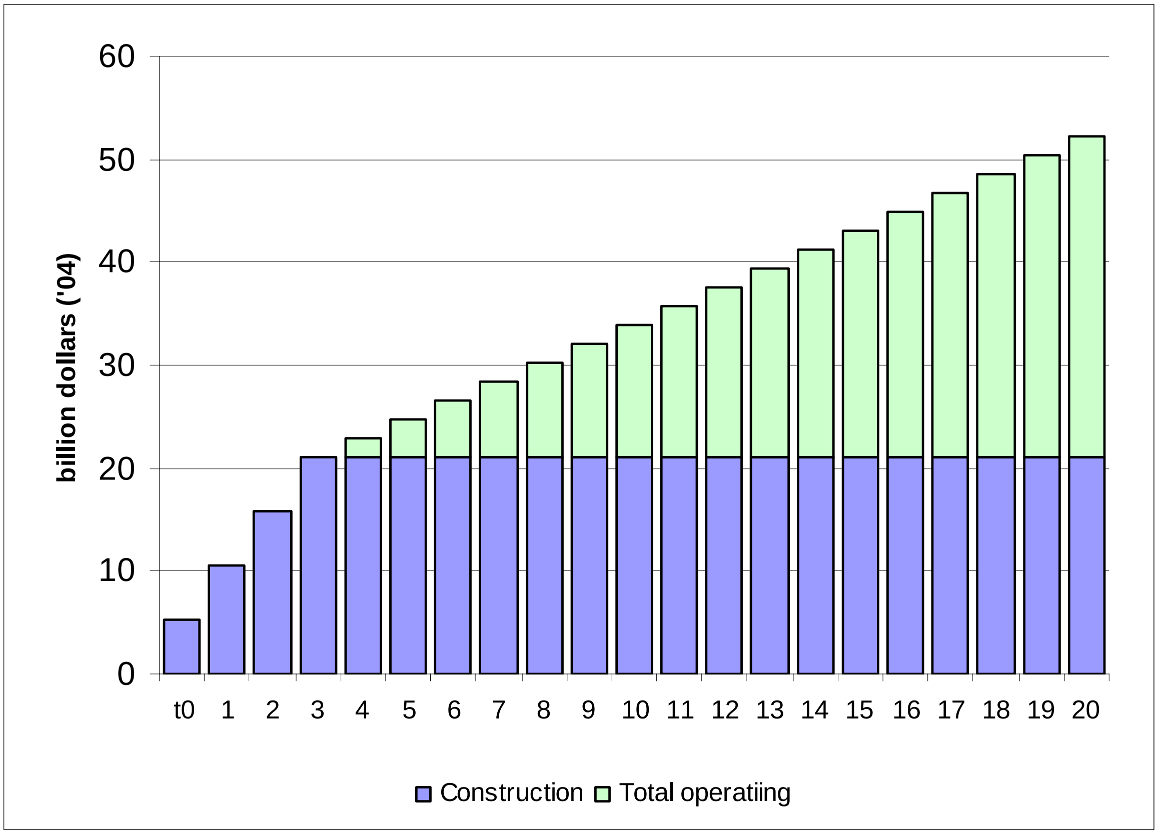
[1] This is the assumed cost of the nth plant; the first plants constructed will be more expensive and these additional costs were not estimated in this study.
[2] The methodological approach is flexible enough to analyze a larger or smaller number of plants coming on-line each year.
[3] Not including transportation or other infrastructure may underestimate the total impact on the economy, jobs, and taxes.

- The \$700 billion does not represent the total costs of the CTL plants, since construction begun in years t_0+17… t_0+20 continues in later years on plants that will come on-line in years t_0+21 to t_0+24, and total O&M costs increase every year through t_0+24.

Figure VI-1
Direct Costs of the CTL Mitigation Option



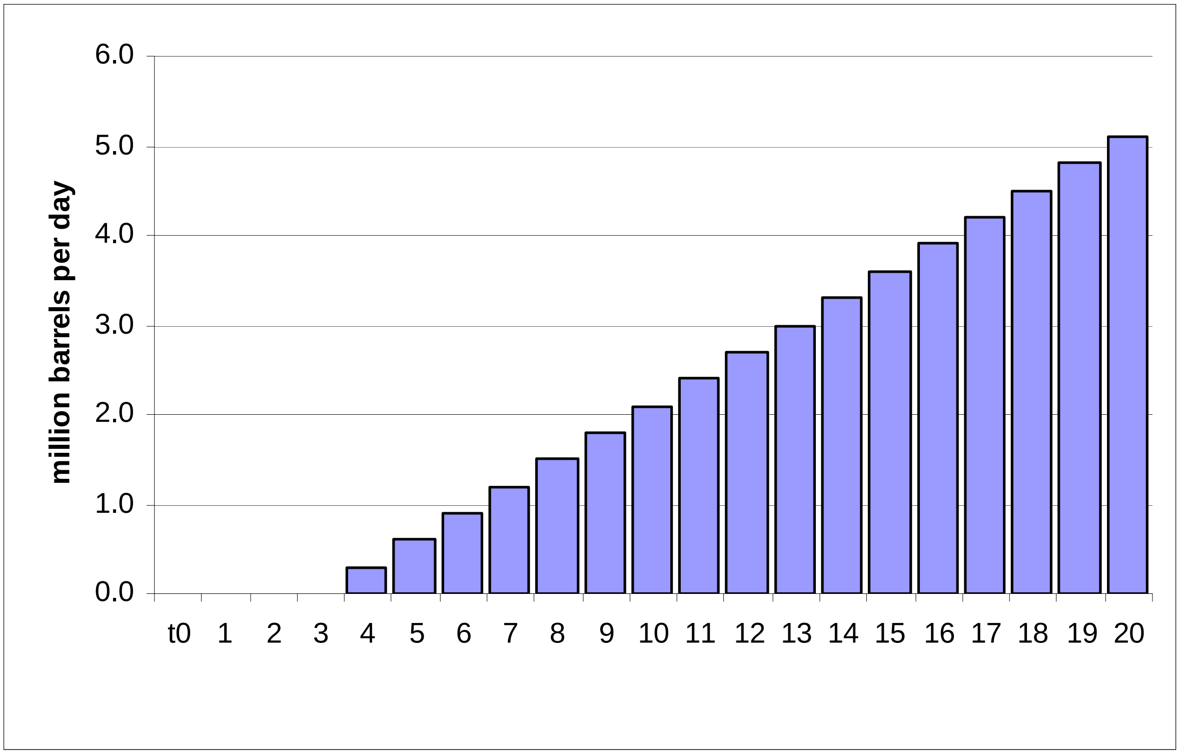
- While our study cuts off at year t_0+20, we assume that the pattern of construction continues beyond that year for purposes of our analysis.

Figure VI-2 shows the liquid fuels production of the CTL plants over the 20-year period and illustrates that:

- Liquid fuels production begins at 300,000 bpd in year t_0+4 as the first set of three plants comes on-line.
- Liquid fuels production increases linearly each year thereafter, as three new CTL plants come on-line annually.
- At year t_0+10, liquid fuels production from the CTL plants totals 2 million bpd.
- At year t_0+20, liquid fuels production from the CTL plants totals 5 million bpd.

- Liquid fuels production will continue to increase beyond t_0+20 as the additional CTL plants for which construction began in years t_0+17… t_0+20 come on-line in years t_0+21 through t_0+24.

Figure VI-2
Liquid Fuels Production From the CTL Plants



VI.F. Impact on Sales, Jobs, and Industries

We estimated the total (direct plus indirect) impacts of the CTL mitigation option and determined that it will likely increase industry sales and employment substantially. As illustrated in Tables VI-2 through VI-5, the CTL scenario:

- Generates \$65 billion in total industry sales in year t_0+10 and more than \$100 billion in year t_0+20.
- Generates 340,000 jobs in year t_0+10 and nearly 500,000 jobs in year t_0 + 20.

While significant, the job estimates must be put into perspective: In 2010, U.S. employment is projected to total 142 million; in 2020 it is projected to total 154 million; in 2030 it is projected to total 166 million. Nevertheless, while there will be job gains and job displacements resulting from the CTL option, the net job change is likely to be strongly positive.

Table VI-2
Top 20 Industries Affected in Year t_0+10 by the CTL Option – Ranked by Sales

Industry	Sales Increase in Year t_0+10 (billions of 2004 dollars)
1. Construction	$14.6
2. Petroleum and coal products	6.2
3. Mining, except oil and gas	4.9
4. Miscellaneous professional, scientific and technical services	3.3
5. Fabricated metal products	2.1
6. Wholesale trade	2.1
7. Chemical products	1.7
8. Truck transportation	1.6
9. Support activities for mining	1.5
10. Nonmetallic mineral products	1.4
11. Oil and gas extraction	1.3
12. Rental and leasing services and lessors of intangible assets	1.3
13. Management of companies and enterprises	1.2
14. Federal Reserve banks, credit intermediation, and related activities	1.2
15. Wood products	1.2
16. Machinery	1.2
17. Retail trade	1.1
18. Primary metals	1.1
19. Rail transportation	1.1
20. Broadcasting and telecommunications	1.1
All other industries	14.1
Total, all industries	$65

As discussed in Chapter IV, we estimated the impacts of the mitigation options on economic output and employment within the 70-order two- and three-digit NAICS code industries. In general, in terms of industry sales and jobs we found that throughout the forecast period the construction, petroleum and coal products, mining, professional, scientific, and technical services, chemical products, and related industries would be major beneficiaries. For example, in terms of total industry sales, as shown in Tables VI-2 and VI-4:

- In year t_0+10, sales in the construction industry increase by $15 billion and in year t_0+20 sales also increase by $15 billion.
- In year t_0+10, sales in the petroleum and coal products industry increase by $6 billion and in year t_0+20 sales increase by $14 billion.
- In year t_0+10, mining industry sales increase by $5 billion and in year t_0+20 sales increase by $11 billion.
- In year t_0+10, sales in the professional, scientific, and technical services industry increase by $3 billion and in year t_0+20 sales in this industry increase by $5 billion.

- In year t_0+10, sales in the chemical products industry increase by \$2 billion and in year t_0+20 sales increase by \$3 billion.

Table VI-3
Top 20 Industries Affected in Year t_0+10 by the CTL Option – Ranked by Employment

Industry	**Job Increases in Year t_0+10** (thousands of jobs)
1. Construction	114
2. Mining, except oil and gas	20
3. Administrative and support services	19
4. Retail trade	17
5. Miscellaneous professional, scientific and technical services	17
6. Truck transportation	12
7. Wholesale trade	12
8. Fabricated metal products	12
9. Other services, except government	10
10. Support activities for mining	7
11. Nonmetallic mineral products	7
12. Wood products	6
13. Other transportation and support activities	6
14. Management of companies and enterprises	6
15. Federal Reserve banks, credit intermediation, and related activities	6
16. Machinery	5
17. State and local government enterprises	5
18. Rail transportation	4
19. Plastics and rubber products	4
20. Forestry, fishing, and related activities	3
All other industries	46
Total, all industries	338

As shown in Tables VI-3 and VI-5, the increases in industry employment in each year are analogous to the increases in industry sales, although there are some differences due to the different productivity and output/employment relationships among industries. With respect to the job increases in different industries:

- In both years t_0+10 and t_0+20, 115,000 jobs are created in the construction industry.
- In year t_0+10, 20,000 jobs are created in the mining industry and in year t_0+20 46,000 jobs are created in this industry.
- In year t_0+10, 17,000 jobs are created in the professional, scientific, and technical services industry and in year t_0+20 24,000 jobs are created in this industry.
- In year t_0+10, 12,000 jobs are created in the trucking industry and in year t_0+20 15,000 jobs are created in this industry.
- In year t_0+10, 19,000 jobs are created in administrative and support services, and in year t_0+20 27,000 jobs are created in this industry.

Table VI-4
Top 20 Industries Affected in Year t_0+20 by the CTL Option – Ranked by Sales

Industry	Sales Increase in Year t_0+20 (billions of 2004 dollars)
1. Construction	$14.7
2. Petroleum and coal products	14.0
3. Mining, except oil and gas	11.4
4. Miscellaneous professional, scientific and technical services	4.6
5. Wholesale trade	3.7
6. Chemical products	3.0
7. Oil and gas extraction	2.8
8. Fabricated metal products	2.8
9. Rail transportation	2.3
10. Rental and leasing services and lessors of intangible assets	2.2
11. Management of companies and enterprises	2.1
12. Support activities for mining	2.1
13. Truck transportation	1.9
14. Machinery	1.9
15. Federal Reserve banks, credit intermediation, and related activities	1.9
16. Utilities	1.8
17. Pipeline transportation	1.6
18. Primary metals	1.6
19. Real estate	1.6
20. Nonmetallic mineral products	1.5
All other industries	21.7
Total, all industries	$101

As noted, construction is the industry in which sales and employment increase the most in all years, although in year t_0+20 this industry accounts for a smaller portion of the increase in sales and jobs than in year t_0+10. Specifically, in this industry:

- In year t_0+10, sales of $15 billion represent 22 percent of total sales of $65 billion.
- In year t_0+20, sales of $15 billion represent 15 percent of total sales of $101 billion.
- In year t_0+10, employment of 114,000 represents 34 percent of the total 338,000 jobs created.
- In year t_0+20, employment of 115,000 represents 23 percent of the total 491,000 jobs created.

Table VI-5
Top 20 Industries Affected in Year t_0+20 by the CTL Option – Ranked by Employment

Industry	Job Increases in Year t_0+20 (thousands of jobs)
1. Construction	115
2. Mining, except oil and gas	46
3. Administrative and support services	27
4. Miscellaneous professional, scientific and technical services	24
5. Retail trade	22
6. Wholesale trade	21
7. Truck transportation	15
8. Fabricated metal products	15
9. Other services, except government	14
10. Management of companies and enterprises	10
11. State and local government enterprises	10
12. Support activities for mining	10
13. Other transportation and support activities	10
14. Federal Reserve banks, credit intermediation, and related activities	9
15. Rail transportation	8
16. Machinery	8
17. Nonmetallic mineral products	8
18. Wood products	6
19. Oil and gas extraction	6
20. Petroleum and coal products	5
All other industries	102
Total, all industries	491

VI.G. Industry Profits

The increase in industry sales generated by the CTL mitigation initiative will create substantial profits for the industries. Applying the estimates of profit margins by detailed industry to the increased sales in each industry indicates that:

- In year t_0+10, the CTL option results in industry profits of approximately $2.8 billion.
- In year t_0+20, the CTL option results in industry profits of approximately $4.5 billion

VI.H. Federal, State, and Local Government Tax Revenues

The increased sales and incomes created by the CTL mitigation option will generate substantial federal, state, and local government tax revenues; specifically:

- In year t_0+10, the CTL option generates approximately $20 billion in tax revenues: $13 billion in federal tax revenues and $7 billion in state and local tax revenues.
- In year t_0+20, the CTL option generates approximately $30 billion in tax revenues: $20 billion in federal tax revenues and $10 billion in state and local tax revenues.

VI.I. Summary of Major CTL Initiative Impacts

The CTL mitigation option modeled here will provide substantial quantities of liquid fuels, will generate large requirements for the products and services of many industries, will generate substantial industry profits, will create large numbers of jobs, and will generate significant federal, state, and local government tax revenues. The major impacts of the CTL option can be summarized as follows:

In year t_0+10, the CTL option:

- Results in the production of 2 million bpd of liquid fuels
- Generates $65 billion in industry sales
- Creates about $3 billion in industry profits
- Generates $13 billion in federal government tax revenues
- Generates $7 billion in state and local government tax revenues.
- Creates 350,000 jobs

In year t_0+20, the CTL option:

- Results in the production of 5 million bpd of liquid fuels
- Generates $100 billion in industry sales
- Creates about $5 billion in industry profits
- Generates $20 billion in federal government tax revenues
- Generates $10 billion in state and local government tax revenues.
- Creates 500,000 jobs

VI.J. Occupational Impacts

We disaggregated the employment generated by the CTL mitigation option into occupations and skills, as illustrated in Table VI-6 for selected occupations in years t_0+10 and t_0+20.[1] The jobs generated are disproportionately concentrated in fields related to the construction, energy, and industrial sectors, reflecting the requirements of the CTL mitigation option and its supporting industries. Thus, disproportionately large numbers of jobs will be generated for various professional, technical, and skilled occupations such as:

[1]Employment was disaggregated among more than 700 individual occupations.

- Accountants and auditors
- Brickmasons and blockmasons
- Carpenters
- Cement masons and concrete finishers
- Civil engineers
- Computer programmers
- Electricians
- Excavating and loading machine operators
- First line construction supervisors
- Heating, air conditioning, and refrigeration mechanics
- Industrial engineers
- Industrial machinery mechanics
- Industrial production managers
- Machinists
- Mechanical engineers
- Mobile heavy equipment mechanics
- Operating engineers
- Plumbers
- Sheet metal workers
- Software engineers
- Structural iron and steel workers
- Tool and die makers
- Welders

Accordingly, the importance of the CTL mitigation option for jobs in some occupations is much greater than in others. Some occupations, such as those listed above, will benefit greatly from the employment requirements generated by the mitigation initiatives. However, it is also important to note that the jobs generated by the CTL mitigation option will be widely distributed among all occupations and skill levels and, while the numbers of jobs created in different occupations differ substantially, employment in virtually all occupations will be generated. The vast majority of the jobs created by the CTL initiative will be standard jobs created, directly and indirectly, for accountants, engineers, bookkeepers, computer analysts, clerks, factory workers, security guards, truck drivers, technicians, sales representatives, analysts, mechanics, etc.

Table VI-6
Occupational Impacts of the Coal Liquefaction Option
(Selected Occupations)

Occupation	Jobs in Year t_0+10	Jobs in Year t_0+20
Accountants and auditors	3,600	5,600
Bookkeeping and accounting clerks	6,900	9,700
Brickmasons and blockmasons	1,700	1,700
Carpenters	6,400	6,600
Cashiers	4,800	6,500
Cement masons and concrete finishers	3,000	3,000
Civil engineers	800	1,000
Computer programmers	1,200	1,900
Construction laborers	12,100	12,600
Cost estimators	2,100	2,200
Drywall and ceiling tile installers	1,800	1,900
Electricians	7,800	8,500
Excavating and loading machine operators	1,400	2,200
Executive secretaries and administrative assistants	4,700	7,000
First line construction supervisors	8,300	6,200
Heating, air conditioning, and refrigeration mechanics	2,500	2,500
Industrial engineers	700	1,000
Industrial machinery mechanics	1,200	2,000
Janitor and cleaners	3,900	5,700
Machinists	1,300	1,900
Management analysts	1,000	1,600
Mechanical engineers	800	1,100
Mobile heavy equipment mechanics	1,000	1,500
Operating engineers	5,300	6,900
Painters	3,300	3,300
Plumbers	5,900	6,100
Security guards	1,900	2,700
Shipping and receiving clerks	2,000	3,000
Sheet metal workers	2,300	2,400
Software engineers	1,400	2,000
Structural iron and steelworks	1,100	1,100
Truck Drivers	9,100	13,500
Welders	2,000	2,800
Total, all occupations	338,000	491,000

VII. OIL SHALE

VII.A. U.S. Oil Shale Resources

Oil shale is sedimentary maristone rock that is embedded with rich concentrations of organic material known as kerogen. U.S. western oil shales contain approximately 15 percent organic material by weight. By heating oil shale to high temperatures, kerogen can be released and converted to a liquid that, once upgraded, can be refined into a variety of liquid fuels, gases, and high value chemical and mineral byproducts.

The United States has vast known oil shale resources that could translate into more than two trillion barrels of known kerogen "oil-in-place."[1] The largest oil shale deposits in the world are concentrated in the Green River Formation in the states of Colorado, Wyoming, and Utah. Estimates of the oil resource in place within the Green River Formation range from 1.5 trillion to 1.8 trillion barrels – about three-quarters of the U.S. total.[2] About 1 trillion barrels are located within the Piceance Basin, which indicates that this 1,200 square mile area in western Colorado holds as much oil as the entire world's proven oil reserves.[3]

Within the Piceance Basin, about a half trillion barrels of oil are contained in deposits yielding more than 25 gallons per ton.[4] Most of the oil shale is contained in deposits more than 500 feet thick and located beneath 50 or more feet of sedimentary rock, although in some cases the deposits are more than 2,000 feet thick and covered by more than 1,000 feet of overburden.[5] The potential yield per surface acre is extremely large, with portions of the basin potentially yielding more than 2.5 million barrels per acre -- well beyond the area concentration of any known oil reserves.[6]

Black, organic-rich shales, produced during the Devonian period, underlie a large portion of the eastern United States, where they are known primarily as a potential source of natural gas.[7] The richest and most accessible deposits are found in Kentucky, Ohio, Indiana, and Tennessee. When heated, these Devonian shales produce oil, but the organic matter yields only about half as much oil as the organic

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[1]U.S. Department of Energy, Office of Naval Petroleum Reserves, *Strategic Significance of America's Oil Shale Resource, Volume I: Assessment of Strategic Issues*, March 2004.
[2]J.R. Dyni, "Geology and Resources of Some World Oil Shale Deposits, *Oil Shale*, Vol. 20, No 3 (2003), pp. 193-252; J.W. Smith, "Oil Shale Resources of the United States," *Mineral and Energy Resources*, Vol. 23, Nos. 6, Colorado School of Mines, 1980.
[3]*BP Statistical Review of World Energy, London, 2005*.
[4]Dyni, op.cit.
[5]J.R. Donnell, "Storehouse of Energy Minerals in the Piceance Basin," in O.J. Taylor, ed., "Oil Shale, Water Resources, and Valuable Minerals of the Piceance Basin, Colorado: The Challenges and Choices of Development," USGS Professional Paper 1310, Washington, D.C., 1987.
[6]Smith, op.cit, and Donnell, op.cit.
[7]See Roger H. Bezdek, "An Energy Policy That Actually Worked," *America's Independent*, August 2002, pp. 10-14.

matter in the Green River shales.[1] In all, the U.S. contains between 60 and 70 percent of world shale oil reserves, followed by Brazil, Russia/FSU, and Australia.[2]

VII.B. Oil Shale Development in the U.S.

Because of the abundance and geographic concentration of the known resource, oil shale has been recognized as a potentially valuable U.S. energy resource since the late 1800s. Early products derived from oil shale included kerosene and lamp oil, paraffin, fuel oil, lubricating oil and grease, naphtha, illuminating gas, and ammonium sulfate fertilizer, and it was recognized as a major source for liquid transportation fuels early in the 20th century. Numerous commercial entities sought to develop oil shale resources, and a commercial U.S. shale oil facility was in operation between 1916 and 1924 in Nevada.[3] The Mineral Leasing Act of 1920 made petroleum and oil shale resources on Federal lands available for development under the terms of federal mineral leases. However, discoveries of more economically producible and refinable crude oil in commercial quantities caused interest in oil shales to decline.

Interest resumed after World War II, when military fuel demand, domestic fuel requirements, and rising fuel prices emphasized the economic and strategic importance of U.S. oil shale resources. Public and private R&D efforts were initiated, including the 1946 U.S. Bureau of Mines Anvil Point, Colorado, oil shale demonstration project.[4] Significant investments were made to define and develop the resource and to develop commercially viable technologies, but major crude oil discoveries in the lower-48 United States, offshore, and in Alaska, as well as other parts of the world reduced the need for shale oil and interest in the resources again decreased.

The 1973 Arab oil embargo and the energy crises of the 1970s gave new impetus to oil shale R&D and commercialization. During the 1970s, related federal R&D increased and a number of oil companies made major investments in western oil shale projects, including The Oil Shale Corp. (TOSCO), Union Oil Co. of California (Unocal), and USBM, a 16-company consortium sponsored by Sohio, Amoco, and others. In the late 1970s, Amoco estimated that its commercial production would be initiated by 1980, with full-scale production of 50,000 to 100,000 bpd targeted for 1982. Projections indicated operating levels of 900,000 bpd by the mid-1980s.

However, by the early 1980s, technological advances and new discoveries of offshore oil resources in the North Sea and elsewhere provided new and diverse sources for U.S. oil imports, and by the mid-1980s oil prices had decreased dramatically. Despite significant investments by U.S. energy companies and numerous improvements in mining, restoration, retorting, and in-situ processes, the costs of oil

[1]Due to considerations of grade, yield, and processing costs, eastern oil shale deposits are less attractive for near-term development than are the western shales.
[2]Outside of the U.S., estimates of oil shale reserves are especially imprecise; see Jean Laherrere, "Review of Oil Shale Data," August 2005.
[3]"Catlin Oil Shale Company, 1916 – 1924," www.elkorose.com/oilshale.
[4]U.S. Department of Energy, Office of Naval Petroleum Reserves, *Strategic Significance of America's Oil Shale Resource, Volume II: Oil Shale Resources, Technology, and Economics*, March 2004.

shale production relative to foreseeable oil prices made continuation of commercial efforts impractical and they were terminated. In 1985 Congress abolished the Synthetic Liquid Fuels Program, which over 40 years had expended $8 billion, and the federal oil shale R&D program was terminated in 1993.[1]

VII.C. Oil Shale Technologies

Processes for producing shale oil generally fall into one of two groups: Mining followed by surface retorting and in-situ retorting or conversion.

Surface Retorting and Mining

The current commercial readiness of surface retorting technology is questionable, and the development of surface retorts that took place during the 1970s and 1980s produced mixed results. Technical viability was demonstrated, but significant scale-up problems were encountered in building and designing commercial systems. Cost information available from projects and available design studies indicate that a first-of-a-kind commercial surface retorting complex is unlikely to be profitable unless real crude oil prices are at least $70 to $95 per barrel (2005 dollars).[2] In addition, surface retorting requires the resolution of significant environmental and water requirement issues.

In-Situ Retorting

In-situ retorting entails heating oil shale in place, extracting the liquid from the ground, and transporting it to an upgrading facility. Various approaches to in-situ retorting were investigated during the 1970s and 1980s. The mainstream methods involved burning a portion of the oil shale underground to produce the heat needed for retorting the remaining oil shale. However, much of this work was not successful encountering serious problems in maintaining and controlling the underground combustion process and avoiding subsurface pollution.

In the early 1980s, researchers at the Shell Oil Houston R&D Center began experimenting with a different type of in-situ retorting, which they named the In-Situ Conversion Process (ICP).[3] In Shell's approach, a volume of shale is heated by electric heaters placed in vertical holes drilled through the entire thickness (more than a thousand feet) of a section of oil shale. Between 15 and 25 heating holes will be drilled per acre, and after heating for two to three years, the targeted volume of the deposit will reach a temperature of between 650 and 700 degrees F. This very slow heating to a

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[1]National Research Council, *Energy R&D at DOE: Was it Worth it?* Washington, D.C., National Academy Press, 2001.
[2]RAND, *Oil Shale Development in the United States: Prospects and Policy Issues*, report prepared for the National Energy Technology Laboratory, 2005, p. 15.
[3]The Shell process is described in Stephen Mut, "The Potential of Oil Shale," presentation at the National Academies workshop "Trends in Oil Supply/Demand and the Potential for Peaking of Conventional Oil Production," Washington, D.C., October, 2005; RAND, op. cit.; and *Strategic Significance of America's Oil Shale Resource, Volume II: Oil Shale Resources, Technology, and Economics*, op. cit..

relatively low temperature (compared with the plus-900 degrees F temperatures common in surface retorting) is sufficient to cause the chemical and physical changes required to release oil from the shale. On an energy basis, about two-thirds of the released product is liquid and one third is a gas similar in composition to natural gas. The released product is gathered in collection wells positioned within the heated zone.[1]

As part of site preparation, Shell plans to use ground-freezing technology to establish an underground barrier around the perimeter of the extraction zone. A "freeze wall" would be created by circulating a refrigerated fluid through a series of wells drilled around the extraction zone. In addition to preventing groundwater from entering the extraction zone, the freeze wall is intended to keep hydrocarbons and other products generated by retorting from leaving the project perimeter during ground heating, product extraction, and post-extraction ground cooling. The site preparation stage also involves the construction of a power plant and power transmission lines needed to supply electricity to the underground heaters.

The oil produced by the ICP will be a premium feedstock that can be sent directly to refineries, without the need for near-site upgrading. Postproduction cleanup involves steam flushing to remove remaining mobile hydrocarbons, ground cooling, removing the freeze wall, and site reclamation.

This approach requires no subsurface mining and thus may be capable of achieving high resource recovery in the deepest and thickest portions of the U.S. oil shale resource. Most important, the Shell in-situ process can be implemented without the massive disturbance to land that would be caused by the only other method capable of high energy/resource recovery -- deep surface mining combined with surface retorting. The footprint of this approach is very small, and when applied to the thickest oil shale deposits of the Piceance Basin, drilling of about 150 acres per year could support sustained production of a half-million barrels of oil per day and 500 billion cubic feet per year of natural gas.[2]

We assumed oil shale facilities similar to what Shell has described, and, we used data from Shell on their ICP process.

VII.D. Specifications for New Oil Shale Facilities

Our oil shale scenario involves a crash program of facility development and construction beginning in year t_0. The basic assumptions for our oil shale scenario were:

[1]Shell has tested its in-situ process at a very small scale on Shell's private holdings in the Piceance Basin. The energy yield of the extracted liquid and gas is equal to that predicted by the standardized assay test, and the heating energy required for this equals about one-sixth the energy value of the extracted product. These indicate that the process may be technically and economically viable. DOE scientists have reviewed the Shell ICP and report that the technology is promising. Confirmation of the technical feasibility of the concept depends on resolution of two technical issues: Controlling groundwater during production and preventing subsurface environmental problems.

[2]U.S. Department of Energy, Office of Naval Petroleum Reserves, op. cit.; RAND, op. cit.

- Technology: In-situ (the Shell In-Situ Conversion Process)
- Output: 2/3 liquids, 1/3 gas[1]
- Each oil shale facility is sized to produce 100,000 bpd of liquid fuels.
- Time until first set of facilities is on-line: t_0+8[2]
- Beginning in t_0+8, three plants come on-line each year.
- Construction will begin on three new facilities per year. The source of the required electricity will be dedicated coal-fired power plants.[3]
- Each facility requires five years construction time – including both construction of the required power plant and oil shale facility development, followed by three years of heating to produce first product.
- The plants are not geographically specified, e.g. they are generic facilities, although they will almost certainly be sited in Colorado, Utah, and Wyoming.
- Energy requirements: Each 100,000 bpd facility will require1 GW of electricity.[4]
- The construction cost of each facility is $8 billion (2004 dollars).[5]
- The O&M costs for each facility will total $500 million (2004 dollars) per year.[6]
- The costs specified do not include those for product transportation, refining, or other infrastructure.

VII.E. Direct Costs and Impacts of the Oil Shale Facilities

The direct costs and impacts resulting from our oil shale scenario are summarized in Figures VII-1 and VII-2. Figure VII-1 shows the direct costs incurred in plant construction and operations over the 20-year period and illustrates that:

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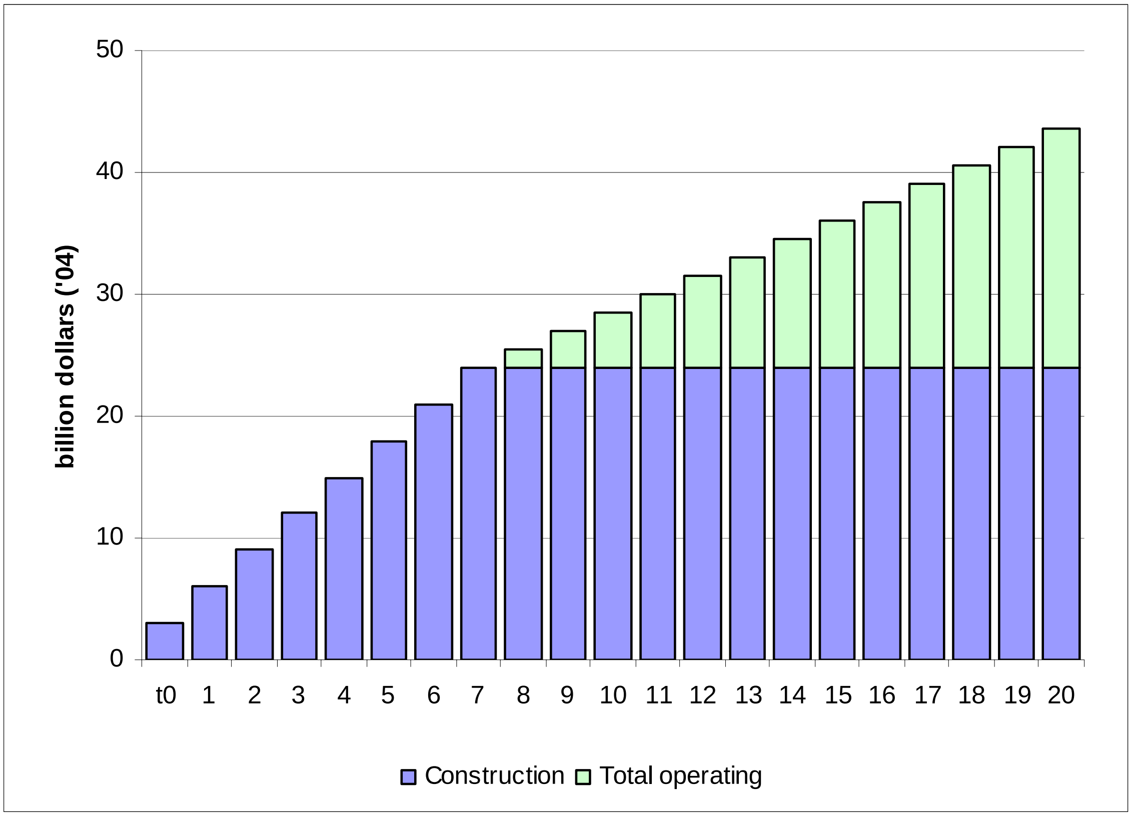
[1]As specified by Stephen Mut. This ratio may be variable.
[2]Even under a crash program, construction of the required electric power plant will require a minimum of four years, after which the in-situ heating can begin. The in-situ heating will require an additional 3-4 years. However, this may be optimistic: At the ASPO-USA World Oil Conference “Beyond Oil: Intelligent Response to Peak Oil Impacts” Denver, Colorado, November 2005 Stephen Mut stated that Shell may be lucky to get the first pilot plant on-line by 2010 and the first commercial plant (of any size) on line by 2015. He stated that the chances of getting to 1M bpd by 2015 are negligible, but, “if things go right,” production could reach 5M bpd by 2030. RAND contends that it will take at least 20 years to get plants of 100,000 bpd on-line; see RAND, op. cit.
[3]Nuclear power plants may be able to provide some of the required electricity.
[4]Stephen Mut, comments at the ASPO-USA World Oil Conference “Beyond Oil: Intelligent Response to Peak Oil Impacts,” op. cit.
[5]This includes the capital costs of all aspects of the oil shale facility, including the dedicated electric power plant required.
[6]This includes the costs of electricity generation.

Figure VII-1
Direct Costs of the Oil Shale Mitigation Option



- All of the costs incurred initially are construction costs (including the construction costs of the required electric power plants), and they increase rapidly beginning in year t_0.
- No O&M costs are incurred until year t_0+8, when the first set of facilities begins operation.[1]
- More than $100 billion in construction costs will be expended by the time the first three facilities begin production of liquid fuels.
- Beginning in year t_0+8, construction costs remain constant at $24 billion per year, since three new facilities are being built each year.
- After year t_0+8, O&M costs rise rapidly as three new facilities come on-line each year.
- Even though annual O&M costs grow rapidly after year t_0+8, they never reach the magnitude of construction costs.
- By year t_0+20, annual O&M costs of $20 billion are 45 percent of the total direct costs incurred that year, and are 83 percent as large as the construction costs in that year.

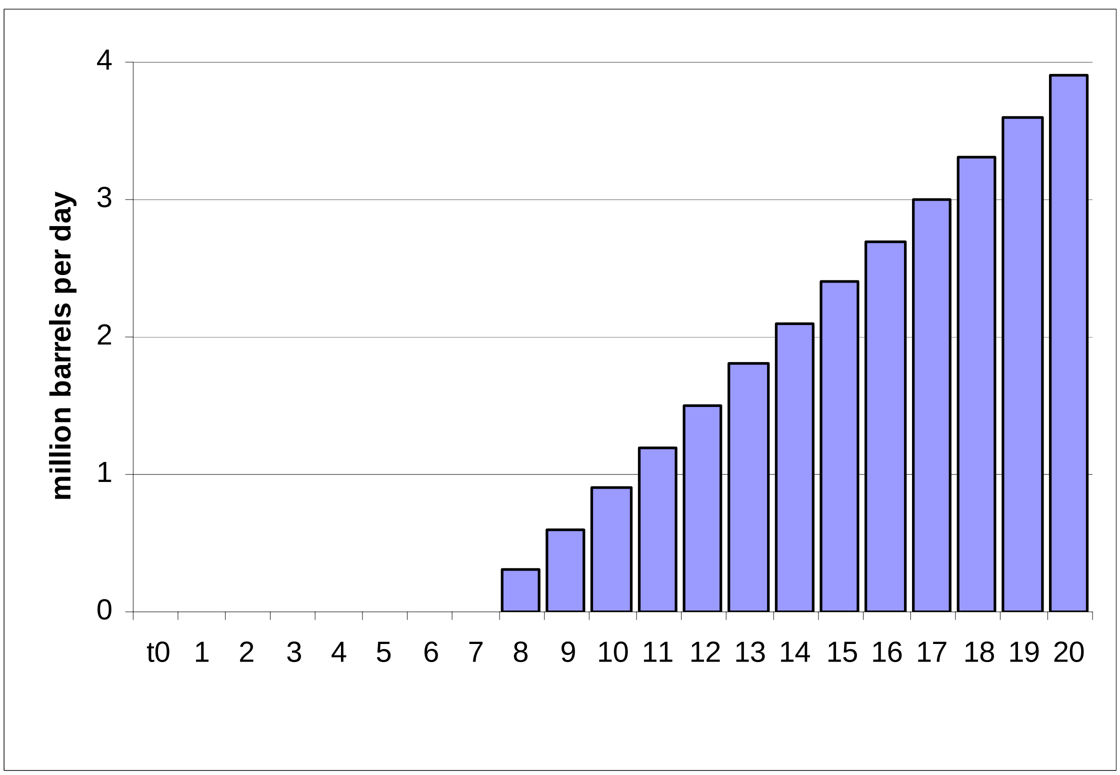
[1]In reality, some operations costs will be incurred prior to year t_0+8, as work on the facility is phased in over a period of several years. Unlike a coal liquefaction plant, there is not a distinct demarcation between construction and operations for an oil shale facility.

- Cumulative construction and O&M costs over the 20-year period total approximately $560 billion (2004 dollars).
- $560 billion does not represent the total costs of the oil shale facilities, since construction begun in years t_0+12… t_0+20 continues in later years on plants that will come on-line in years t_0+21 to t_0+28, and total O&M costs increase every year through t_0+28 and beyond.

Figure VII-2 shows the liquid fuels production of the oil shale facilities over the 20-year period and illustrates that:

- Liquid fuels production begins at 300,000 bpd in year t_0+8 as the first set of three facilities comes on-line.
- Liquid fuels production increases linearly each year thereafter, as three new oil shale facilities come on-line annually.
- At year t_0+10, liquid fuels production from the oil shale facilities plants totals 900,000 bpd.
- At year t_0+20, liquid fuels production from the oil shale facilities totals about 4 million bpd.
- Liquid fuels production will continue to increase beyond t_0+20 as the additional oil shale facilities for which construction began in years t_0+12… t_0+20 come on-line in years t_0+21 to t_0+28.

Figure VII-2
Liquid Fuels Production From the Oil Shale Facilities



VII.F. Impact on Sales, Jobs, and Industries

We estimated the total (direct plus indirect) impacts of the oil shale mitigation option and determined that it will likely increase industry sales and employment substantially. As illustrated in Tables VII-1 through VII-4, the oil shale scenario:

- Generates more than $50 billion in total industry sales in year t_0+10 and nearly $80 billion in year t_0+20.
- Generates 280,000 jobs in year t_0+10 and 350,000 jobs in year t_0 + 20.

While significant, the job estimates must be put into perspective: In 2010, U.S. employment is projected to total 142 million; in 2020 it is projected to total 154 million; in 2030 it is projected to total 166 million. Nevertheless, while there will be job gains and job displacements resulting from the oil shale option, the net job change is likely to be strongly positive.

Table VII-1
Top 20 Industries Affected in Year t_0+10 by the Oil Shale Option – Ranked by Sales

Industry	Sales Increase in Year t_0+10 (billions of 2004 dollars)
1. Construction	$12.8
2. Oil and gas extraction	6.0
3. Petroleum and coal products	3.5
4. Miscellaneous professional, scientific and technical services	2.6
5. Fabricated metal products	1.7
6. Wholesale trade	1.5
7. Utilities	1.2
8. Rental and leasing services and lessors of intangible assets	1.2
9. Nonmetallic mineral products	1.1
10. Chemical products	1.1
11. Retail trade	1.0
12. Pipeline transportation	1.0
13. Federal Reserve banks, credit intermediation, and related activities	1.0
14. Truck transportation	.9
15. Broadcasting and telecommunications	.9
16. Administrative and support services	.8
17. Primary metals	.8
18. Wood products	.8
19. Real estate	.8
20. Management of companies and enterprises	.8
All other industries	$9.8
Total, all industries	$51

As discussed in Chapter IV, we estimated the impacts of the mitigation options on economic output and employment within the 70 two- and three-digit NAICS code industries. In general, in terms of industry sales and jobs we found that throughout the forecast period the construction, oil and gas extraction, petroleum and coal products, professional, scientific, and technical services, fabricated metal products, and related industries would be major beneficiaries. For example, in terms of total industry sales, as shown in Tables VII-1 and VII-3:

- In year t_0+10, sales in the construction industry increase by $13 billion and in year t_0+20 sales also increase by $13 billion.
- In year t_0+10, oil and gas extraction industry sales increase by $6 billion and in year t_0+20 sales increase by $13 billion.
- In year t_0+10, sales in the petroleum and coal products industry increase by $4 billion and in year t_0+20 sales increase by $11 billion.
- In year t_0+10, sales in the professional, scientific, and technical services industry increase by $3 billion and in year t_0+20 sales in this industry also increase by $3 billion.

Table VII-2
Top 20 Affected in Year t_0+10 by the Oil Shale Option – Ranked by Employment

Industry	**Job Increases in Year t_0+10** (thousands of jobs)
1. Construction	100
2. Administrative and support services	15
3. Retail trade	14
4. Miscellaneous professional, scientific and technical services	14
5. Oil and gas extraction	13
6. Fabricated metal products	9
7. Other services, except government	9
8. Wholesale trade	9
9. Truck transportation	7
10. State and local government enterprises	6
11. Nonmetallic mineral products	6
12. Federal Reserve banks, credit intermediation, and related activities	5
13. Wood products	4
14. Management of companies and enterprises	4
15. Waste management and remediation services	3
16. Rental and leasing services and lessors of intangible assets	3
17. Machinery	3
18. Plastics and rubber products	3
19. Other transportation and support activities	3
20. State and local general government	3
All other industries	49
Total, all industries	281

- In year t_0+10, sales in the fabricated metal products industry increase by $2 billion and in year t_0+20 sales also increase by $2 billion.

As shown in Tables VII-2 and VII-4, the increases in industry employment in each year are analogous to the increases in industry sales, although there are some differences due to the different productivity and output/employment relationships among industries. With respect to the job increases in different industries:

- In both years t_0+10 and t_0+20, about 100,000 jobs are created in the construction industry.
- In year t_0+10, 20,000 jobs are created in the mining industry and in year t_0+20, 46,000 jobs are created in this industry.
- In year t_0+10, 14,000 jobs are created in the professional, scientific, and technical services industry and in year t_0+20 17,000 jobs are created in this industry.
- In year t_0+10, 13,000 jobs are created in the oil and gas extraction industry and in year t_0+20 29,000 jobs are created in this industry.

Table VII-3
Top 20 Industries Affected in Year t_0 + 20 by the Oil Shale Option – Ranked by Sales

Industry	**Sales Increase in Year t_0+20** (billions of 2004 dollars)
1. Oil and gas extraction	$13.4
2. Construction	12.5
3. Petroleum and coal products	11.4
4. Utilities	3.4
5. Miscellaneous professional, scientific and technical services	3.4
6. Wholesale trade	2.1
7. Pipeline transportation	2.0
8. Fabricated metal products	1.9
9. Chemical products	1.9
10. Rental and leasing services and lessors of intangible assets	1.8
11. Federal Reserve banks, credit intermediation, and related activities	1.4
12. Management of companies and enterprises	1.2
13. Nonmetallic mineral products	1.2
14. Truck transportation	1.2
15. Administrative and support services	1.1
16. Broadcasting and telecommunications	1.1
17. Real estate	1.0
18. Primary metals	1.0
19. Retail trade	.9
20. Wood products	.9
All other industries	12.8
Total, all industries	$78

- In year t_0+10, 15,000 jobs are created in administrative and support services, and in year t_0+20, 19,000 jobs are created in this category.

As noted, construction is the industry in which sales and employment increase the most in both year t_0+10 and year t_0+20, although in year t_0+20, this industry accounts for a smaller portion of the increase in sales and jobs than in year t_0+10. Specifically, in this industry:

- In year t_0+10, increased sales of $13 billion represent 25 percent of total increased sales of $51 billion.
- In year t_0+20, increased sales of $13 billion represent 17 percent of total increased sales of $78 billion.
- In year t_0+10, increased employment of 100,000 represents 36 percent of the total 281,000 jobs created.
- In year t_0+20, increased employment of 98,000 represents 28 percent of the total 350,000 jobs created.

Table VII-4
Top 20 Industries Affected in Year t_0+20 by the Oil Shale Option – Ranked by Employment

Industry	**Job Increases in Year t_0+20** (thousands of jobs)
1. Construction	98
2. Oil and gas extraction	29
3. Administrative and support services	19
4. Miscellaneous professional, scientific and technical services	17
5. State and local government enterprises	16
6. Retail trade	13
7. Wholesale trade	12
8. Other services, except government	11
9. Fabricated metal products	10
10. Truck transportation	9
11. Federal Reserve banks, credit intermediation, and related activities	6
12. Nonmetallic mineral products	6
13. Management of companies and enterprises	6
14. Wood products	5
15. Rental and leasing services and lessors of intangible assets	5
16. Petroleum and coal products	4
17. Computer systems design and related services	4
18. Utilities	4
19. Legal services	4
20. Waste management and remediation services	4
All other industries	68
Total, all industries	350

VII.G. Industry Profits

The increase in industry sales generated by the oil shale mitigation initiative will create substantial profits for the industries. Applying estimates of profit margins by detailed industry to the increased sales in each industry indicates that:

- In year t_0+10, the oil shale option results in industry profits of approximately $2.4 billion.
- In year t_0+20, the oil shale option results in industry profits of approximately $3.8 billion.

VII.H. Federal, State, and Local Government Tax Revenues

The increased sales and incomes created by the oil shale mitigation option will generate substantial federal, state, and local government tax revenues; specifically:

- In year t_0+10, the oil shale option generates approximately $15 billion in tax revenues: $10 billion in federal government tax revenues and $5 billion in state and local government tax revenues.
- In year t_0+20, the oil shale option generates approximately $23 billion in tax revenues: $15 billion in federal government tax revenues and $8 billion in state and local government tax revenues.

VII.I. Summary of Major Oil Shale Initiative Impacts

In sum, the bottom line is that the oil shale mitigation option modeled here will provide substantial quantities of liquid fuels, will generate large requirements for the products and services of many industries, will generate substantial industry profits, will create large numbers of jobs, and will generate significant federal, state, and local government tax revenues. The major impacts of the oil shale option can be summarized as follows:

In year t_0+10, the oil shale option:

- Results in the production of nearly 1 million bpd of liquid fuels
- Generates $50 billion in industry sales
- Creates about $2.5 billion in industry profits
- Generates $10 billion in federal government tax revenues
- Generates $5 billion in state and local government tax revenues
- Creates 280,000 jobs

In year t_0+20, the oil shale option:

- Results in the production of 4 million bpd of liquid fuels
- Generates $80 billion in industry sales
- Creates nearly $4 billion in industry profits

- Generates $15 billion in federal government tax revenues
- Generates $8 billion in state and local government tax revenues
- Creates 350,000 jobs

VII.G. Occupational Impacts

We disaggregated the employment generated by the oil shale mitigation option into occupations and skills, as illustrated in Table VII-5 for selected occupations in years t_0+10 and t_0+20.[1] The jobs generated are disproportionately concentrated in fields related to the construction, energy, and industrial sectors, reflecting the requirements of the oil shale mitigation option and its supporting industries. Thus, disproportionately large numbers of jobs will be generated for various professional, technical, and skilled occupations such as:

- Accountants and auditors
- Carpenters
- Civil engineers
- Computer support specialists
- Computer systems analysts
- Construction managers
- Electricians
- Glaziers
- Industrial engineers
- Industrial machinery mechanics
- Machinists
- Mechanical engineers
- Mobile heavy equipment mechanics
- Oil and gas derrick operators
- Oil and gas rotary drill operators
- Operating engineers
- Pipelayers
- Plumbers

Accordingly, the importance of the oil shale mitigation option for jobs in some occupations is much greater than in others. Some occupations, such as those listed above, will benefit greatly from the employment requirements generated by the mitigation initiatives.

[1]Employment was disaggregated among more than 700 individual occupations.

Table VII-5
Occupational Impacts of the Oil Shale Option

Occupation	Jobs in Year t_0+10	Jobs in Year t_0+20
Accountants and auditors	2,800	4,100
Carpenters	5,800	5,700
Civil engineers	600	800
Computer support specialists	1,000	1,300
Computer systems analysts	900	1,200
Construction laborers	10,500	10,500
Construction managers	2,200	2,200
Cost estimators	1,800	1,800
Customer service representatives	4,600	6,200
Electrical power-line installers and repairers	600	1,000
Electricians	6,700	6,900
First-line office and administrative supervisors/managers	3,300	4,600
Glaziers	500	500
Industrial engineers	500	700
Industrial machinery mechanics	800	1,300
Inspectors and testers	1,400	1,800
Janitors and cleaners	3,400	4,600
Machinists	1,000	1,200
Maintenance and repair workers	3,500	5,000
Mechanical engineers	600	800
Mobile heavy equipment mechanics	700	1,000
Oil and gas derrick operators	400	900
Oil and gas rotary drill operators	400	900
Oil and gas roustabouts	900	1,900
Office clerks, general	7,000	10,600
Operating engineers	4,100	5,000
Packaging and filling machine operators and tenders	1,100	1,400
Painters, construction and maintenance	2,900	2,800
Paving, surfacing, and tamping equipment operators	600	600
Pipelayers	600	600
Plasterers and stucco masons	800	800
Plumbers	5,100	5,200
Production, planning, and expediting clerks	600	800
Purchasing agents	600	700
Receptionists and information clerks	1,700	2,100
Reinforcing iron and rebar workers	400	400
Sales representatives, wholesale and manufacturing	3,200	4,100
Secretaries	4,400	5,800
Security guards	1,700	2,100
Telecommunications equipment installers and repairers	800	1,000
Tile and marble setters	600	500
Total, all occupations	281,000	350,000

However, it is also important to note that the jobs generated by the oil shale mitigation option will be widely distributed among all occupations and skill levels and, while the numbers of jobs created in different occupations differ substantially, employment in virtually all occupations will be generated. The vast majority of the jobs created by the oil shale initiative will be standard jobs created, directly and indirectly, for accountants, engineers, bookkeepers, computer analysts, clerks, factory workers, security guards, truck drivers, technicians, sales representatives, analysts, mechanics, etc.

VIII. ENHANCED OIL RECOVERY

VIII.A. Background

Management of an oil reservoir over its multi-decade life is influenced by a range of factors, including 1) actual and expected future oil prices; 2) production history, geology, and status of the reservoir; 3) cost and character of production-enhancing technologies; 4) timing of enhancements; 5) the financial condition of the operator; 6) political and environmental circumstances, 7) an operator's other investment opportunities, etc.

Improved Oil Recovery (IOR) is used to varying degrees on all oil reservoirs. IOR encompasses a variety of methods to increase oil production and to expand the volume of recoverable oil from reservoirs. Options include in-fill drilling, hydraulic fracturing, horizontal drilling, advanced reservoir characterization, enhanced oil recovery (EOR), and a myriad of other methods that can increase the flow and recovery of liquid hydrocarbons. IOR can also include many seemingly mundane efficiencies introduced in daily operations.[1]

A particularly notable opportunity to increase production from existing U.S. oil reservoirs is the use of enhanced oil recovery technology (EOR), also known as tertiary recovery. EOR is usually initiated after primary and secondary recovery have produced most of what they can provide. Primary production is the process by which oil flows to the surface because it is naturally under pressure underground. Secondary recovery involves the injection of water into a reservoir to force additional oil to the surface.

EOR has been practiced since the 1950s, particularly in the United States. The process that likely has the largest U.S. potential is miscible flooding wherein carbon dioxide (CO_2) is injected into an oil reservoir, providing additional pressure and solvency to move residual oil. CO_2 flooding can increase oil recovery by 7-15 percent of original oil in place (OOIP).[2]

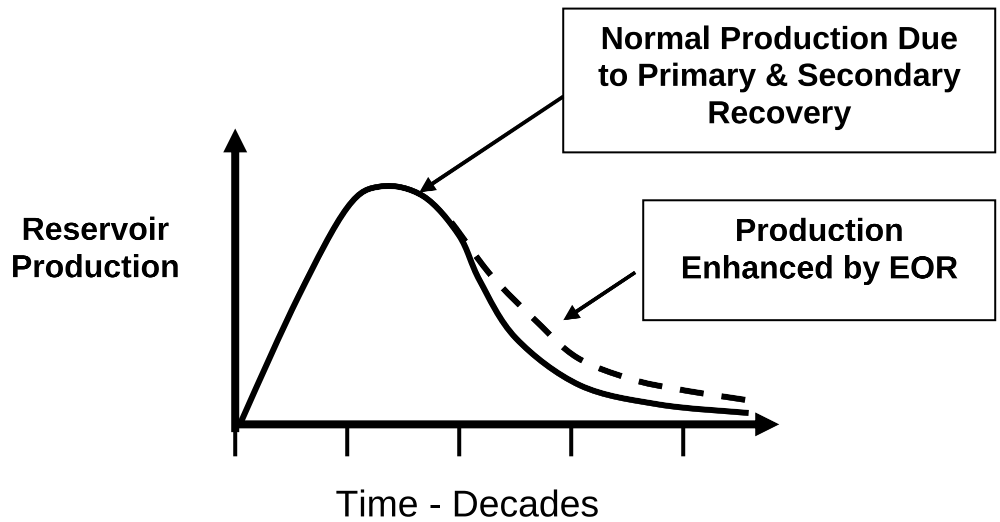
Because EOR is relatively expensive, it has not been widely deployed in the past. However, in a world of long-term, high oil prices, it has significant potential for additional oil production in the U.S. and elsewhere.[3]

Enhanced oil recovery is typically not applied to a conventional oil reservoir until after oil production has peaked, so EOR is not likely to increase reservoir peak production. However, EOR can increase total recoverable conventional oil, so

[1]Williams, B. "Progress in IOR Technology, Economics Deemed Critical to Staving Off World's Oil Production Peak", *Oil and Gas Journal,* August 4, 2003.
[2]Ibid; National Research Council. *Fuels to Drive Our Future*. National Academy Press. 1990; "EOR Continues to Unlock Oil Resources," *Oil and Gas Journal,* April 12, 2004.
[3]In addition, large volumes of CO_2 may be available should carbon storage and sequestration efforts progress in response to environmental and global warming initiatives.

production from the reservoirs to which it is applied does not decline as rapidly as would otherwise be the case. This concept is illustrated in Figure VIII-1.

Figure VIII-1. The Timing of EOR Applications



Most of the CO_2 used for EOR has come from naturally occurring reservoirs in Colorado from which it has been transported via pipeline to west Texas and New Mexico. Because of the potential for CO_2 EOR, investments are being made to produce high concentration streams of CO_2 from industrial facilities such as natural gas processing, fertilizer, ethanol, and hydrogen plants. For example, a demonstration at the Dakota Gasification Company's plant in Beulah, North Dakota is producing CO_2 that is being delivered via a 204-mile pipeline to the Weyburn oil field in Saskatchewan, Canada. Encana, the field's operator, is injecting the CO_2 to extend the field's productive life, hoping to add another 25 years and as much as 130 million barrels of oil that might otherwise have been abandoned.[1]

VIII.B. Historical Development

Over the past two decades, CO_2 EOR production in the U.S. increased more than eight-fold, from less than 25,000 bpd in 1985 to over 200,000 bpd in 2004. More than 90 percent of injectant was supplied from three natural CO_2 deposits in Colorado: McElmo Dome, Sheep Mountain, and Bravo Dome. In addition, a small fraction of the Permian basin CO_2 supply has come from anthropogenic sources -- CO_2 streams from four natural gas processing facilities in the Val Verde sub-basin, located in the southern Permian basin. In contrast, most of the CO_2 supply in the Rocky Mountain and Mid-continent regions came from anthropogenic sources such as natural gas processing plants and fertilizer production facilities.

[1]www.encana.com/operations/technology.

VIII.C. Potential in the U.S.

In U.S. basins recently studied, primary and secondary oil recovery methods will bypass an estimated 205 billion barrels of oil, a fraction of which could potentially be extracted using EOR.[1] This substantial target represents about two-thirds of U.S. OOIP in already discovered fields. According to the *Oil and Gas Journal*, CO_2 flooding is the fastest growing form of enhanced oil recovery in the United States, producing an estimated 206,000 barrels per day in 2004, mostly in the Permian Basin of West Texas and New Mexico.[2] This represents about four percent of total U.S. oil production of 5.4 million bpd.

A series of studies recently completed for DOE identified 533 large oil reservoirs that screen favorably for CO_2 EOR using state-of-the-art technology.[3] The studies also evaluated the performance of CO_2 EOR projects conducted over the past 30 years. This experience was extrapolated to reservoirs in six study regions and suggesting that 43 billion barrels of additional oil might be recoverable with today's CO_2 EOR technology (See Table VIII-1). Further advancements could conceivably increase this total.

The DOE study estimated that CO_2 EOR could facilitate an additional 2 to 3 million barrels per day of U.S. oil production by 2025. However, overcoming the barriers to the wider use of state-of-the-art CO_2 EOR technologies will require a variety of initiatives, such as establishing low-cost, reliable "EOR-ready" CO_2 supplies from both natural and industrial sources.[4] This could include capturing low CO_2 concentration emissions from electric power generation plants and other sources, such as coal liquefaction plants.

VIII.D. Specifications for EOR Mitigation Option

Building on these recent studies, our EOR scenario is based on a crash program to rapidly expand capacity for enhanced oil recovery beginning in year t_0. Our assumptions for this EOR scenario are:

- CO_2 miscible flooding
- Application in existing oil fields throughout the U.S.

[1] "Oil Exploration & Production Program: Enhanced Oil Recovery," www.fe.doe.gov/programs/oilgas/eor/
[2] *Recovering "Stranded Oil" Can Substantially Add to U.S. Oil Supplies: Six Reports Examine Basin-Oriented Strategies,* U.S. Department of Energy, Office of Fossil Energy, Office of Oil and Natural Gas, April 2005.
[3] Ibid.
[4] Recovering "Stranded Oil" Can Substantially Add to U.S. Oil Supplies, op. cit.

Table VIII-1
CO_2 EOR Technically Recoverable Resource Potential From Six Areas Assessed

Basin/Area	Number of Large Reservoirs Assessed	All Reservoirs (Six Areas Assessed) (Billion Barrels)		
		OOIP*	ROIP**	Technically Recoverable
California	88	83.3	57.3	5.2
Gulf Coast	205	60.8	36.4	10.1
Oklahoma	63	60.3	45.1	9.0
Illinois	46	9.4	5.8	0.7
Alaska	32	67.3	45.0	12..4
Louisiana Offshore (Shelf)	99	28.1	15.7	5.9
Total	**533**	**309.2**	**205.3**	**43.3**

*Original oil in place, in all reservoirs in basin/area.
**Remaining oil in place, in all reservoirs in basin/area.

Source: U.S. Department of Energy and Advanced Resources International, 2005.

- CO_2 from geographically diverse natural and anthropogenic sources including CTL plants, utilities, and other processing and production facilities
- No limit on the availability of capital, personnel, drilling rigs, etc.
- A time lag of three years before crash program EOR production begins
- Incremental production of 175,000 bpd beginning in t_0+4 and increasing by an additional 175,000 bpd every year thereafter for the forecast period
- Cost estimates include CO_2 procurement and other infrastructure

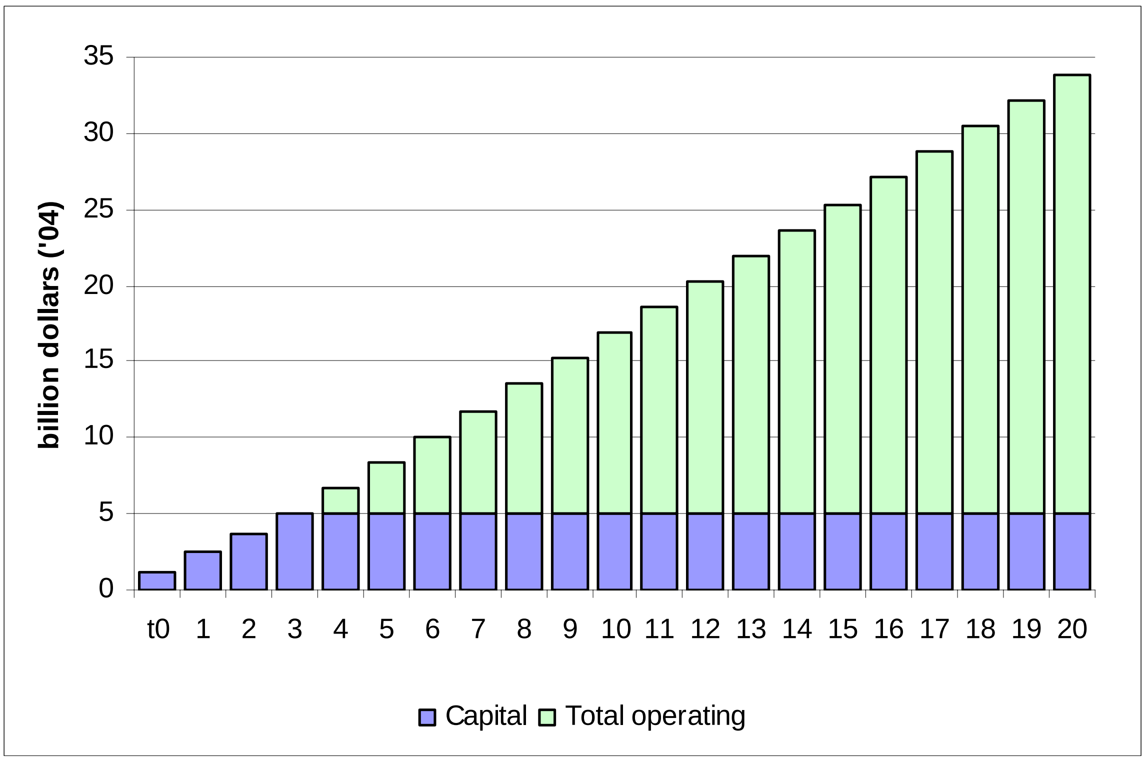
VIII.E. Direct Costs and Impacts of the EOR Facilities

The direct costs and impacts resulting from the EOR scenario are summarized in Figures VIII-2 and VIII-3. Figure VIII-2 shows the direct costs incurred in EOR construction and operations over the 20-year period and illustrates that:

- All costs incurred initially are for drilling and construction, which increase rapidly beginning in year t_0.

- No O&M costs are incurred until year t_0+4, when enhanced oil recovery begins.[1]
- Nearly $15 billion in drilling and construction costs will be expended by the time the first facilities begin enhanced oil recovery.
- Beginning in year t_0+4, construction costs remain constant at $5 billion per year.
- After year t_0+4, O&M costs rise rapidly as additional EOR facilities come on-line each year.
- By year t_0+6, annual O&M costs of $5 billion comprise 50 percent of the total direct costs incurred that year, and are equal to the construction costs in that year.
- After t_0+6, O&M costs exceed drilling and construction costs: By year t_0+12 O&M costs are three times as large as drilling and construction costs, and by year t_0+20 O&M costs are six times as large.

Figure VIII-2
Direct Costs of the EOR Mitigation Option



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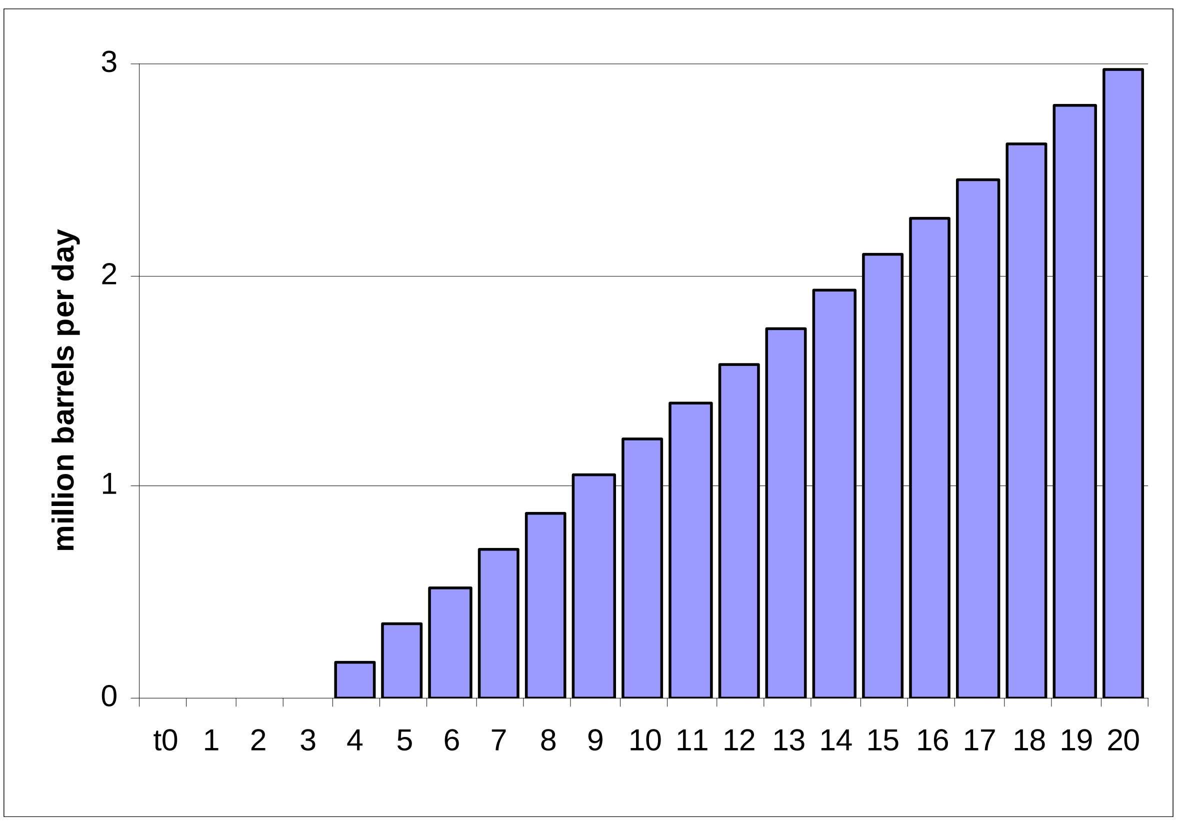
[1]In reality, some operations costs will be incurred prior to year t_0+4, as EOR is phased in over a period of several years. This is unlike a coal liquefaction plant, in which there is a distinct cutoff point between construction and operations.

- Cumulative drilling, construction and O&M costs over the 20-year period total approximately $360 billion (2004 dollars).
- The $360 billion does not represent the total costs of the EOR facilities, since drilling and construction begun in years t_0+16… t_0+20 continues in later years on EOR projects that will come on-line in years t_0+21 to t_0+24, and total O&M costs increase every year through t_0+24.

Figure VIII-3 shows the enhanced oil recovery over the 20-year period and illustrates that:

- Enhanced oil recovery from this scenario begins at 175,000 bpd in year t_0+4 as the first EOR facilities come on-line.
- Enhanced oil recovery increases at a constant rate of 175,000 bpd each year thereafter, as new EOR facilities come on-line annually.
- At year t_0+10, EOR totals 1.2 million bpd.
- At year t_0+20, EOR totals 3 million bpd.

Figure VIII-3
Enhanced Oil Recovery From the EOR Option



- Enhanced oil recovery will continue to increase beyond t_0+20 as the additional EOR facilities for which construction began in years t_0+16… t_0+20 come on-line in years t_0+21 to t_0+24. This analysis simply stops counting after year t_0+20.
- The maximum production of crash program EOR was not estimated in this study. Rather, we assumed that the rate can continue to increase over the forecast period.

VIII.F. Impact on Sales, Jobs, and Industries

We estimated the total (direct plus indirect) impacts of the EOR mitigation option and determined that it will likely increase industry sales and employment substantially. As illustrated in Tables VIII-2 through VIII-5, the EOR scenario:

- Generates more than $30 billion in total industry sales in year t_0+10 and more than $60 billion by year t_0+20
- Generates 130,000 jobs by year t_0+10 and 235,000 jobs in year t_0+ 20

Table VIII-2
Top 20 Industries Affected in Year t_0 + 10 by the EOR Option – Ranked by Sales

Industry	**Sales Increase in Year t_0+10** (billions of 2004 dollars)
1. Oil and gas extraction	$8.1
2. Petroleum and coal products	3.1
3. Construction	2.6
4. Pipeline transportation	1.8
5. Miscellaneous professional, scientific and technical services	1.6
6. Rental and leasing services and lessors of intangible assets	1.2
7. Chemical products	.8
8. Wholesale trade	.8
9. Fabricated metal products	.7
10. Federal Reserve banks, credit intermediation, and related activities	.7
11. Management of companies and enterprises	.6
12. Administrative and support services	.6
13. Utilities	.5
14. Real estate	.5
15. Broadcasting and telecommunications	.5
16. Waste management and remediation services	.5
17. Primary metals	.4
18. Machinery	.4
19. Other services, except government	.4
20. Nonmetallic mineral products	.3
All other industries	4.7
Total, all industries	$31

Table VIII-3
Top 20 Industries Affected in Year t_0 + 10 by the EOR Option – Ranked by Employment

Industry	**Job Increases in Year t_0+10** (thousands of jobs)
1. Construction	20
2. Oil and gas extraction	17
3. Administrative and support services	10
4. Miscellaneous professional, scientific and technical services	8
5. Other services, except government	5
6. Wholesale trade	5
7. Fabricated metal products	4
8. Retail trade	4
9. Federal Reserve banks, credit intermediation, and related activities	3
10. Management of companies and enterprises	3
11. Computer systems design and related services	3
12. Rental and leasing services and lessors of intangible assets	3
13. State and local government enterprises	3
14. Truck transportation	2
15. Waste management and remediation services	2
16. Legal services	2
17. Pipeline transportation	2
18. Nonmetallic mineral products	2
19. State and local general government	2
20. Machinery	2
All other industries	26
Total, all industries	127

While significant, the job estimates must be put into perspective: In 2010, U.S. employment is projected to total 142 million; in 2020 it is projected to total 154 million; in 2030 it is projected to total 166 million. Nevertheless, while there will be job gains and job displacements resulting from the EOR option, the net job change is likely to be strongly positive.

As discussed in Chapter IV, we estimated the impacts of the mitigation options on economic output and employment within the 70 two- and three-digit NAICS code industries. In general, in terms of industry sales and jobs we found that throughout the forecast period the construction, oil and gas extraction, petroleum and coal products, professional, scientific, and technical services, wholesale trade, fabricated metal products, computer systems design, pipeline transportation, and related industries would be major beneficiaries of the EOR scenario. For example, in terms of total industry sales, as shown in Tables VII-2 and VII-4:

- In year t_0+10, oil and gas extraction industry sales increase by $8 billion and in year t_0+20 sales increase to $19 billion.

- In year t_0+10, sales in the petroleum and coal products industry increase by $3 billion and in year t_0+20 sales increase by $7 billion.
- In year t_0+10, sales in the construction industry increase by $3 billion and in year t_0+20 sales also increase by $3 billion.
- In year t_0+10, sales in the pipeline transportation industry increase by $2 billion and in year t_0+20 sales increase by $4 billion.
- In year t_0+10, sales in the professional, scientific, and technical services industry increase by $2 billion and in year t_0+20 sales in this industry increase to $3 billion.

Table VIII-4
Top 20 Industries Affected in Year t_0 + 20 by the EOR Option – Ranked by Sales

Industry	Sales Increase in Year t_0+20 (billions of 2004 dollars)
1. Oil and gas extraction	$18.5
2. Petroleum and coal products	7.0
3. Pipeline transportation	3.5
4. Construction	3.1
5. Miscellaneous professional, scientific and technical services	3.0
6. Rental and leasing services and lessors of intangible assets	2.6
7. Chemical products	1.7
8. Wholesale trade	1.5
9. Management of companies and enterprises	1.4
10. Federal Reserve banks, credit intermediation, and related activities	1.4
11. Fabricated metal products	1.3
12. Utilities	1.3
13. Administrative and support services	1.0
14. Waste management and remediation services	.9
15. Real estate	.9
16. Broadcasting and telecommunications	.9
17. Primary metals	.8
18. Machinery	.8
19. Other services, except government	.7
20. Computer systems design and related services	.7
All other industries	12.8
Total, all industries	$61

As shown in Tables VIII-3 and VIII-5, the increases in industry employment in each year are analogous to the increases in industry sales, although there are some differences due to the different productivity and output/employment relationships among industries. With respect to the job increases in different industries:

- In year t_0+10, 17,000 jobs are created in the oil and gas extraction industry and in year t_0+20, 39,000 jobs are created in this industry.

- In year t_0+10, 20,000 jobs are created in the construction industry and in year t_0+20, 25,000 jobs are created in this industry.
- In year t_0+10, 10,000 jobs are created in the administrative and supports services industry and in year t_0+20, 19,000 jobs are created in this industry.
- In year t_0+10, 8,000 jobs are created in the professional, scientific, and technical services industry and in year t_0+20 16,000 jobs are created in this industry.
- In year t_0+10, 4,000 jobs are created in the fabricated metal products industry and in year t_0+20 7,000 jobs are created in this industry.
- In year t_0+10, 5,000 jobs are created in wholesale trade and in year t_0+20 9,000 jobs are created in this industry.
- In every industry, more jobs are created in t_0+20 than in year t_0+10.

Table VIII-5
Top 20 Industries Affected in Year t_0 + 20 by the EOR Option – Ranked by Employment

Industry	**Job Increases in Year t_0+20** (thousands of jobs)
1. Oil and gas extraction	39
2. Construction	25
3. Administrative and support services	19
4. Miscellaneous professional, scientific and technical services	16
5. Other services, except government	9
6. Wholesale trade	9
7. Fabricated metal products	7
8. Management of companies and enterprises	7
9. Federal Reserve banks, credit intermediation, and related activities	6
10. Rental and leasing services and lessors of intangible assets	6
11. Computer systems design and related services	6
12. State and local government enterprises	6
13. Retail trade	5
14. Waste management and remediation services	5
15. Truck transportation	4
16. Legal services	4
17. Pipeline transportation	3
18. State and local general government	3
19. Machinery	3
20. Insurance carriers and related activities	3
All other industries	49
Total, all industries	234

VIII.G. Industry Profits

The increase in industry sales generated by the EOR mitigation initiative will create substantial profits for the industries. Applying estimates of profit margins by detailed industry to the increased sales in each industry indicates that:

- In year t_0+10, the EOR option results in increased industry profits of approximately $1.4 billion.
- In year t_0+20, the EOR option results in increased industry profits of approximately $2.9 billion.

VIII.H. Federal, State, and Local Government Tax Revenues

The increased sales and incomes created by the EOR mitigation option will generate substantial federal, state, and local government tax revenues; specifically:

- In year t_0+10, the EOR option generates approximately $9 billion in increased tax revenues: $6 billion in federal government tax revenues and $3 billion in state and local government tax revenues.
- In year t_0+20, the EOR option generates approximately $18 billion in increased tax revenues: $12 billion in federal government tax revenues and $6 billion in state and local government tax revenues.

VIII.I. Summary of Major EOR Initiative Impacts

In sum, the bottom line is that the EOR mitigation option modeled here will provide substantial quantities of liquid fuels, will generate large requirements for the products and services of many industries, will generate substantial industry profits, will create large numbers of jobs, and will generate significant federal, state, and local government tax revenues. The major impacts of the enhanced oil recovery option can be summarized as follows:

In year t_0+10, the EOR option:

- Results in the production of more than 1 million bpd of liquid fuels
- Generates $30 billion in industry sales
- Creates about $1.5 billion in industry profits
- Generates $6 billion in federal government tax revenues
- Generates $3 billion in state and local government tax revenues.
- Creates 130,000 jobs

In year t_0+20, the EOR option:

- Results in the production of 3 million bpd of liquid fuels
- Generates more than $60 billion in industry sales
- Creates nearly $3 billion in industry profits

- Generates $12 billion in federal government tax revenues
- Generates $6 billion in state and local government tax revenues
- Creates 235,000 jobs

VIII.J. Occupational Impacts

We disaggregated the employment generated by the EOR mitigation option into occupations and skills, as illustrated in Table VIII-6 for selected occupations in years t_0+6 and t_0+20.[1] The jobs generated are disproportionately concentrated in fields related to the construction, energy, and industrial sectors, reflecting the requirements of the EOR mitigation option and its supporting industries. Thus, disproportionately large numbers of jobs will be generated for various professional, technical, and skilled occupations such as:

- Accountants and auditors
- Civil engineers
- Computer programmers
- Computer systems analysts
- Electricians
- Engineering managers
- Financial managers
- Geoscientists
- Industrial machinery mechanics
- Mobile heavy equipment mechanics
- Oil and gas derrick operators,
- Oil and gas rotary drill operators,
- Oil, gas, and mining service unit operators
- Petroleum engineers
- Petroleum pump system and refinery operators
- Plumbers
- Operating engineers
- Welders

Accordingly, the importance of the EOR mitigation option for jobs in some occupations is much greater than in others. Some occupations, such as those listed above, will benefit greatly from the employment requirements generated by the mitigation initiatives. This is hardly surprising, for most of these jobs are clearly related to the energy, scientific, and industrial sectors.

[1] Employment was disaggregated among more than 700 individual occupations.

Table VIII-6
Occupational Impacts of the EOR Option
(Selected Occupations)

Occupation	Jobs in Year t_0+6	Jobs in Year t_0+20
Accountants and auditors	1,700	3,500
Bookkeeping, accounting, and auditing clerks	2,700	5,000
Civil engineers	300	600
Computer programmers	600	1,200
Computer systems analysts	600	1,200
Construction laborers	2,400	3,100
Cost estimators	400	600
Crushing and grinding machine operators and tenders	300	600
Customer service representatives	2,700	5,200
Electricians	1,600	2,300
Executive secretaries and administrative assistants	2,100	4,100
Engineering managers	300	600
Extraction workers' assistants	700	1,400
Financial managers	700	1,400
First-line construction and extraction supervisors/managers	2,000	3,500
Geoscientists	300	600
Industrial machinery mechanics	500	1,100
Janitors and cleaners	2,100	4,000
Laborers and stock movers	2,900	5,500
Landscaping and grounds keeping workers	1,000	1,900
Maintenance and repair workers	2,000	4,000
Mobile heavy equipment mechanics	400	800
Oil and gas derrick operators,	500	1,100
Oil and gas rotary drill operators,	500	1,100
Oil and gas roustabouts	1,000	2,300
Oil, gas, and mining service unit operators	600	1,200
Petroleum engineers	300	800
Petroleum pump system and refinery operators	500	1,200
Plumbers	1,100	1,500
Operating engineers	1,600	2,900
Sales representatives, wholesale and manufacturing	1,500	2,700
Secretaries	2,200	4,100
Security guards	1,100	2,100
Truck drivers	2,900	5,500
Welders	700	1,200
Wellhead pumpers	300	800
Total, all occupations	127,000	234,000

However, it is important to note that the jobs generated by the EOR mitigation option will be widely distributed among all occupations and skill levels and, while the numbers of jobs created in different occupations differ substantially, employment in virtually all occupations will be generated. The vast majority of the jobs created by the

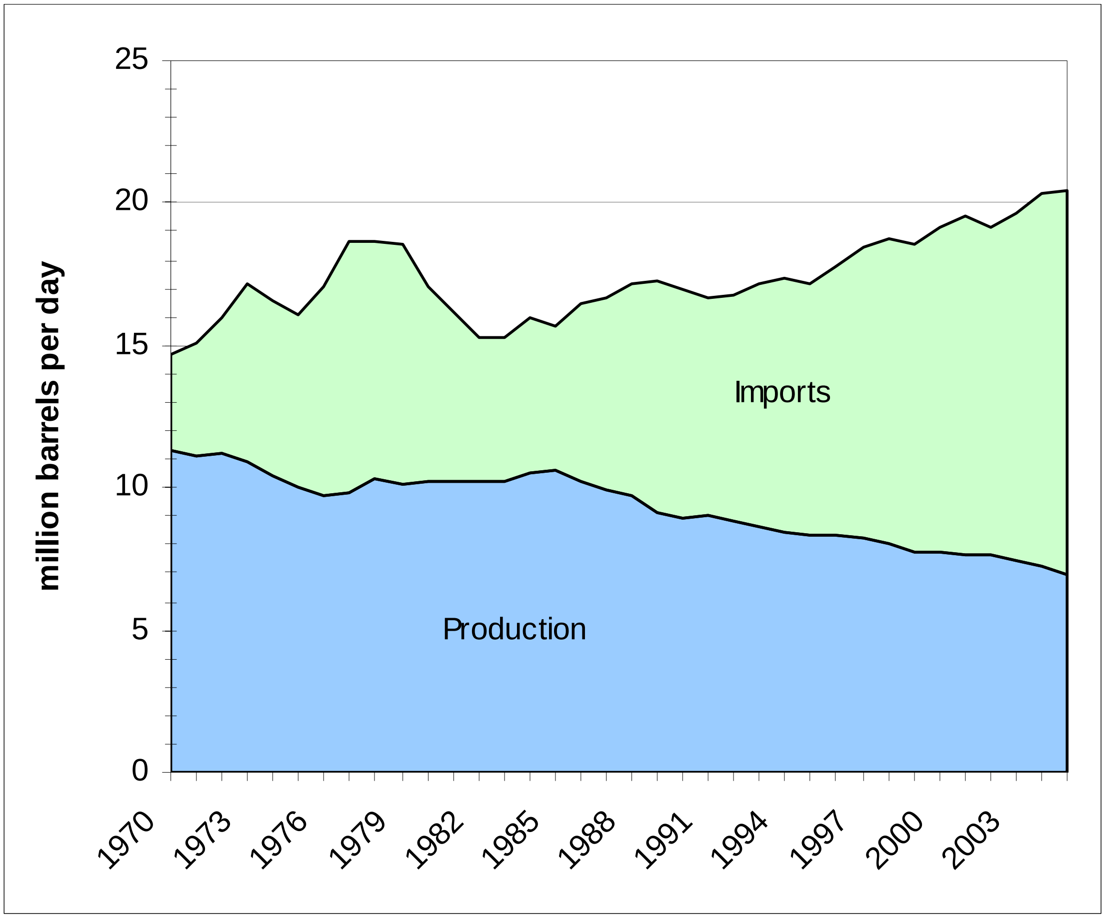
EOR initiative will be standard jobs created directly and indirectly for accountants, engineers, bookkeepers, computer analysts, clerks, factory workers, security guards, truck drivers, technicians, sales representatives, analysts, mechanics, etc.

IX. MITIGATION OPTIONS AND U.S. OIL IMPORTS

IX.A. Petroleum Supply in the U.S.

Total U.S. consumption of crude oil and petroleum products has increased greatly over the last 35 years, expanding from 14.7 million barrels per day (MM bpd) in 1970 to an expected level of 20.4 bpd in 2005 – an increase of nearly 40 percent. As shown in Figure IX-1, two supply interruptions in 1973-74 and 1979 brought a number of changes to the U.S. economy and the way that petroleum was used. However, U.S. oil consumption has steadily and consistently increased since the early 1980s.

Figure IX-1
U.S. Petroleum Supply, 1970-2005



This increase in consumption occurred despite a peak in U.S. domestic petroleum production. In 1970, the domestic sources of U.S. petroleum and petroleum products reached their historical peak at 11.3 MM bpd. Since that time, U.S. petroleum production has declined, reaching an estimated level of 6.9 MM bpd in 2005. However, there was a plateauing of production from 1977 through 1988 when production remained at an average of 10.2 MM bpd and did not deviate more than 400,000 bpd from that level over the entire 12-year period. This was due largely to new production from the Alaskan North Slope. Since 1988, U.S. domestic production has declined steadily after Alaskan production went into decline.

The U.S. has relied on petroleum imports to satisfy its growing demand: Imports have risen more than 300 percent over the period, from a level of 3.4 MM bpd in 1970 to an estimated level of 13.5 MM bpd in 2005. Despite two supply disruptions, negative impacts on the U.S. economy, constraints on foreign policy, and compromises to national security, the U.S. has allowed imports to rise from 23 percent of total supply in 1970 to over 60 percent in 2005.

IX.B. Sources of U.S. Imports

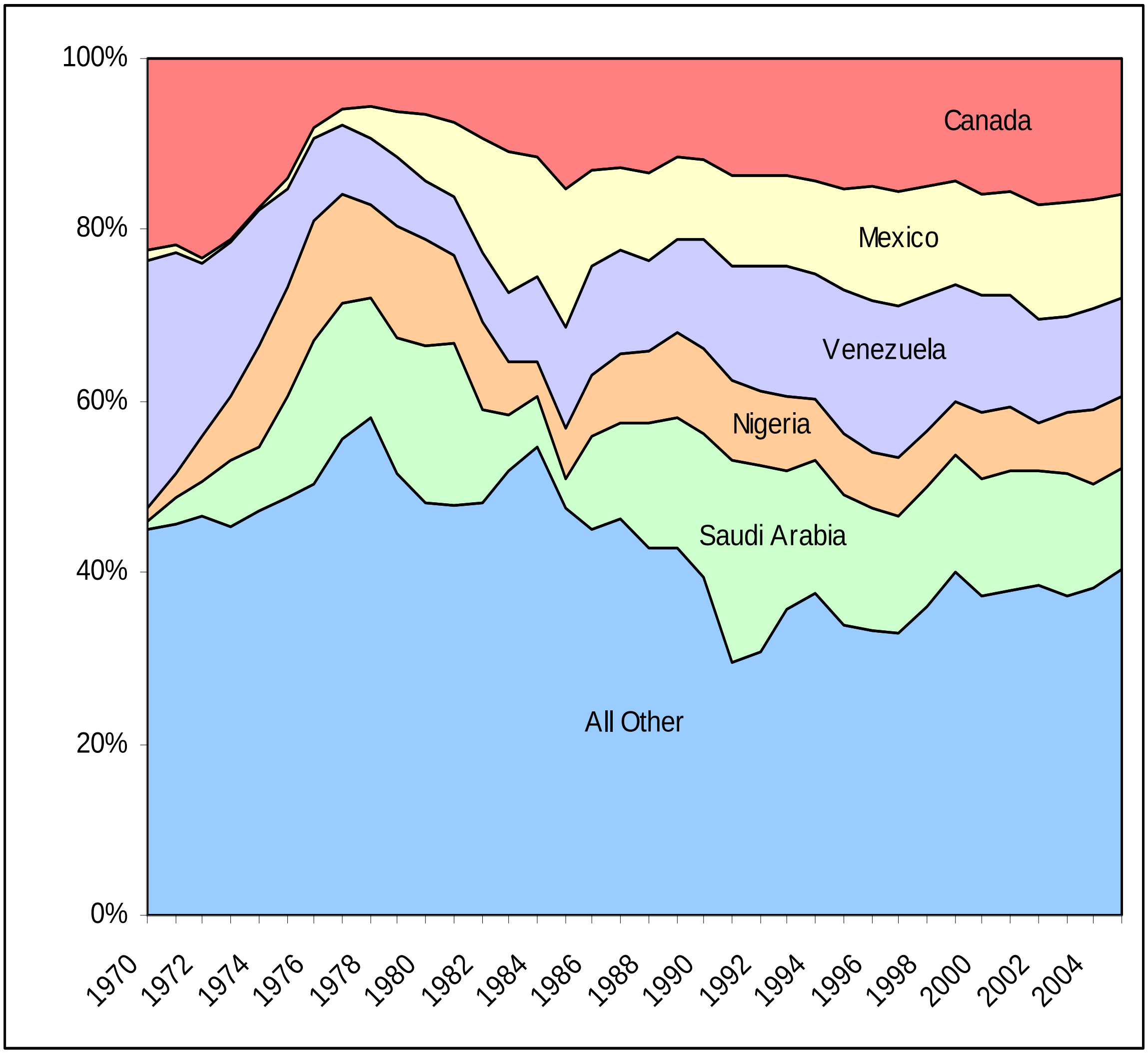
Over this 36-year period, the foreign sources of these imports has changed somewhat, but five countries in particular have consistently provided the majority of imports, as shown in Figure X-2. While Venezuela and Canada provided most of U.S. oil imports in the early 1970's, the mix in 2005 was somewhat more varied. Canada currently supplies around 16 percent of U.S. oil imports (2.1 MM bpd), Mexico, Saudi Arabia and Venezuela about 12 percent (just over 1.6 MM bpd each), and Nigeria supplies just over eight percent (1.1 MM bpd) for a total of about 60 percent of the nation's total petroleum imports.

Fortunately for the U.S., the two countries supplying the most oil imports are also the only two countries that share borders with the U.S. In addition, both Mexico and Canada are also major trading partners with the U.S. as signatory members of NAFTA, and to a certain extent, major parts of the economies of all three counties are intertwined, including technology, agriculture, manufacturing, and labor markets. However, those shared commercial and geopolitical interests are not the case with most of the other suppliers of petroleum consumed in the U.S. Saudi Arabia, Nigeria, and even Venezuela currently present a wide range of geopolitical challenges to the U.S. Of the dozens of other countries that supply petroleum to the U.S. some are friendly towards U.S. interests, some are not, but all will almost certainly sell petroleum to the highest bidder.[1]

It will be extremely difficult, if not impossible, for the U.S. to become "energy independent" in the true sense of the phrase anytime in the coming three decades. As this study demonstrates, the best that the country can realistically achieve over a twenty year period is to become more secure by instituting efficiency improvements and by developing its own domestic non-conventional petroleum resources.

[1] In economic terms, the location of U.S. oil supply sources is not critical, since there is one integrated international oil market and all buyers must access supplies at competitive prices.

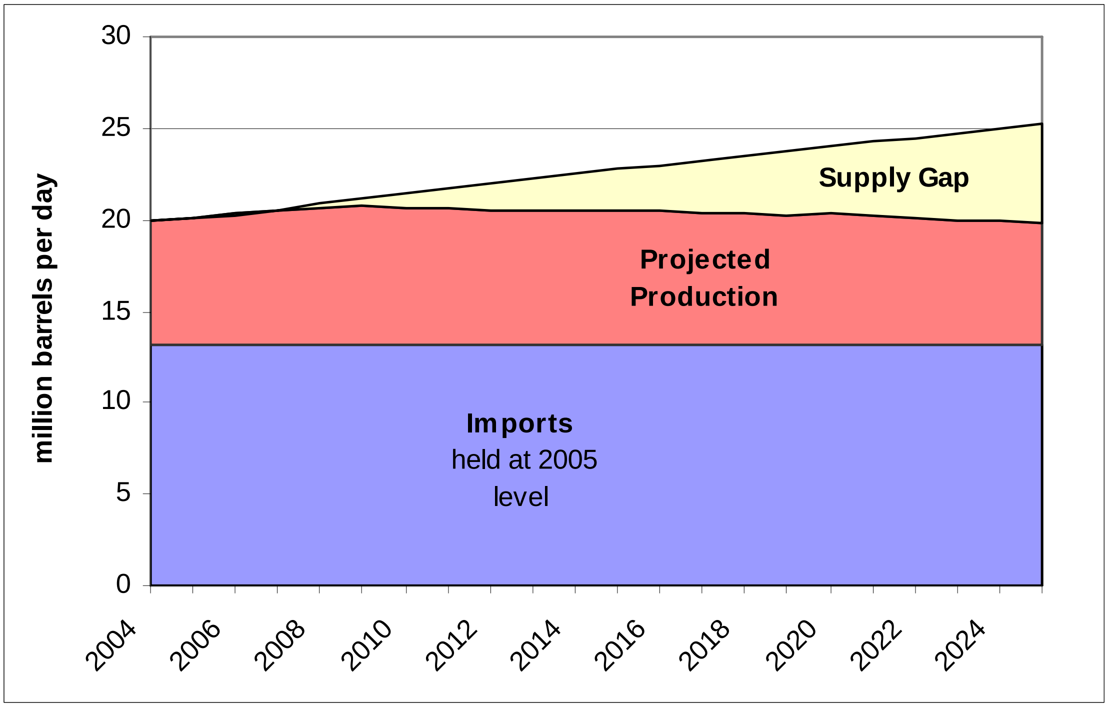
Figure IX-2
U.S. Petroleum Imports by Country, 1970-2005



IX.C. One Petroleum Import Management Scenario: Maintaining the Current Level of Imports

If petroleum imports were maintained at the current level of about 13 MM bpd and all future demand above that level was met by domestic efficiency improvements or new non-conventional supply sources, what would be the gap? To answer that question, we used the Energy Information Administration AEO 2005 forecast and, specifically, the very high oil price case, since we believe that it reflects the tightening of world oil supply consistent with approaching a world oil production peak. Their forecast incorporates a $48.00 per barrel oil price (constant 2003$), and it shows an increase in forecast U.S. petroleum requirements to a level just over 25 MM bpd by 2025 with domestic production decreasing to 6.7 MM bpd. If imports were held constant at the 2004 level of 13.1 MM bpd, domestic production and mitigation must make up for a required level of 12.1 MM bpd by 2025 as shown in Figure IX-3. Since EIA forecasts project domestic production levels decreasing to 6.7 MM bpd, the "gap" that needs to be filled is about 2.5 MM bpd in 2016 and about 5.3 MM bpd in 2025. The question is: Can our hypothesized crash programs of vehicle fuel efficiency and domestic substitute fuels development meet that gap?

Figure IX-3
Domestic Petroleum Supply Gap, 2004-2025



Source: Energy Information Administration, National Energy Technology Laboratory, and MISI; 2006.

IX.D. Impacts of the Mitigation Options

The total fuel savings and production resulting from crash programs involving all four options in year t_0 + 10 is approximately 5 MM bpd and in year t_0 + 20 is about 14 MM bpd. Thus, if the crash mitigation programs envisioned here were to be initiated in 2006, it may be possible to stabilize U.S. oil imports at no more than 13 MM bpd in both 2016 and 2025, representing significant reductions in U.S. oil imports, providing greater U.S. energy security.

However, it should be noted that these relatively optimistic estimates depend critically upon the crash mitigation option programs being started in 2006. If crash program implementation is delayed five years until 2011 for example, then our mitigation options would change the total level of U.S. imports from the current 13 MM bpd to about 15 MM bpd in 2016 and about 12 MM bpd in 2025.

X. OCCUPATIONAL JOB IMPACTS

We disaggregated the employment generated by the mitigation options into occupations and skills, as illustrated in Table X-1 and Figure X-1 for selected occupations in year t_0+20.[1] The jobs generated are disproportionately concentrated in fields related to the construction, energy, and industrial sectors, reflecting the requirements of the mitigation options and their supporting industries. Thus, disproportionately large numbers of jobs will be generated for various professional, technical, and skilled occupations such as:

- Civil engineers
- Computer-controlled machine tool operators
- Construction supervisors and managers
- Oil and gas derrick operators
- Electricians
- Electrical and electronics engineers
- Geoscientists
- Industrial engineers
- Machinists
- Mechanical engineers
- Operating engineers
- Petroleum engineers
- Petroleum system and refinery operators
- Pipelayers
- Plumbers
- Oil and gas drill operators
- Sheet metal workers
- Software engineers
- Tool and die makers
- Welders

Accordingly, the importance of the mitigation options for jobs in some occupations is much greater than in others. Some occupations, such as those listed above, will benefit greatly from the employment requirements generated by the mitigation initiatives. This is hardly surprising, for most of these jobs are clearly related to the construction, energy, scientific, and industrial sectors.

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[1]Employment was disaggregated among more than 700 individual occupations.

Table X-1
Occupational Job Impacts of the Four Mitigation Options in Year t_0+20
(Selected Occupations)

Occupation	Jobs
Accountants and auditors	16,700
Architects	1,500
Bookkeeping, accounting, and auditing clerks	27,200
Brickmasons and blockmasons	3,000
Carpenters	17,000
Cashiers	15,200
Cement masons and concrete finishers	6,400
Civil engineers	2,700
Computer-controlled machine tool operators	2,500
Computer programmers	5,800
Computer systems analysts	5,700
Computer support specialists	6,000
Continuous mining machine operators	2,100
Cost estimators	5,100
Construction laborers	26,700
Construction supervisors/managers	20,700
Customer service representatives	27,200
Derrick operators, oil and gas	3,800
Electricians	18,700
Electrical and electronic equipment assemblers	4,300
Electrical and electronics engineers	4,100
Engineering managers	3,300
Excavating and loading machine and dragline operators	4,900
Executive secretaries and administrative assistants	20,600
Financial managers	7,200
Geological and petroleum technicians	1,500
Geoscientists	2,000
Graphic designers	1,800
Human resources and labor relations specialists	1,700
Industrial engineers	3,500
Industrial machinery mechanics	5,900
Industrial production managers	3,300
Inspectors and testers	9,700
Janitors and cleaners	18,200
Laborers and stock movers	33,600
Machinists	7,000
Management analysts	4,800
Mechanical engineers	3,900
Mobile heavy equipment mechanics	3,700
Network and computer systems administrators	2,000
Office clerks	39,300
Operating engineers and other construction equipment operators	15,200
Petroleum engineers	2,600
Petroleum pump system operators, refinery operators, and gaugers	4,300
Pipelayers	1,500
Production assistants	9,500

Production supervisors/managers	13,900
Plumbers and pipefitters	13,100
Purchasing agents	3,600
Receptionists and information clerks	8,600
Rotary drill operators, oil and gas	3,600
Roustabouts, oil and gas	7,600
Sales managers	3,800
Security guards	8,600
Service unit operators, oil, gas, and mining	4,200
Sheet metal workers	5,400
Shipping and receiving clerks	9,400
Software engineers	11,100
Stock clerks	10,900
Structural iron and steel workers	2,300
Team assemblers	22,200
Tool and die makers	2,000
Truck drivers	33,200
Welders	8,400
Wellhead pumpers	2,600
Total, all occupations	1,386,000

However, it is also important to note that the jobs generated by the mitigation options will be widely distributed among virtually all occupations and skill levels and, while the numbers of jobs created in different occupations differ substantially, employment in virtually all occupations will be generated. The vast majority of the jobs created by the mitigation initiatives will be standard jobs created, directly and indirectly, for accountants, engineers, bookkeepers, computer analysts, clerks, factory workers, security guards, truck drivers, technicians, sales representatives, analysts, mechanics, etc. For example, Table X-1 shows that the four mitigation options combined will likely generate in year t_0+20:

- More jobs for office clerks (39,300) than for software engineers (11,100)
- More jobs for construction laborers (26,700) than for operating engineers (15,200)
- More jobs for janitors (18,200) than for industrial production managers (3,300)
- More jobs for security guards (8,600) than for civil engineers (2,700)
- More jobs for accountants and auditors (16,700) than for machinists (7,000)
- More jobs for truck drivers (33,200) than for petroleum and refinery operators (4,300)
- More jobs for financial managers (7,200) than for industrial engineers (3,500)
- More jobs for management analysts (4,800) than for geologic and petroleum technicians (1,500)

- More jobs for cashiers (15,200) than for geoscientists (2,000)
- More jobs for stock clerks (10,900) than for sheet metal workers (5,400)

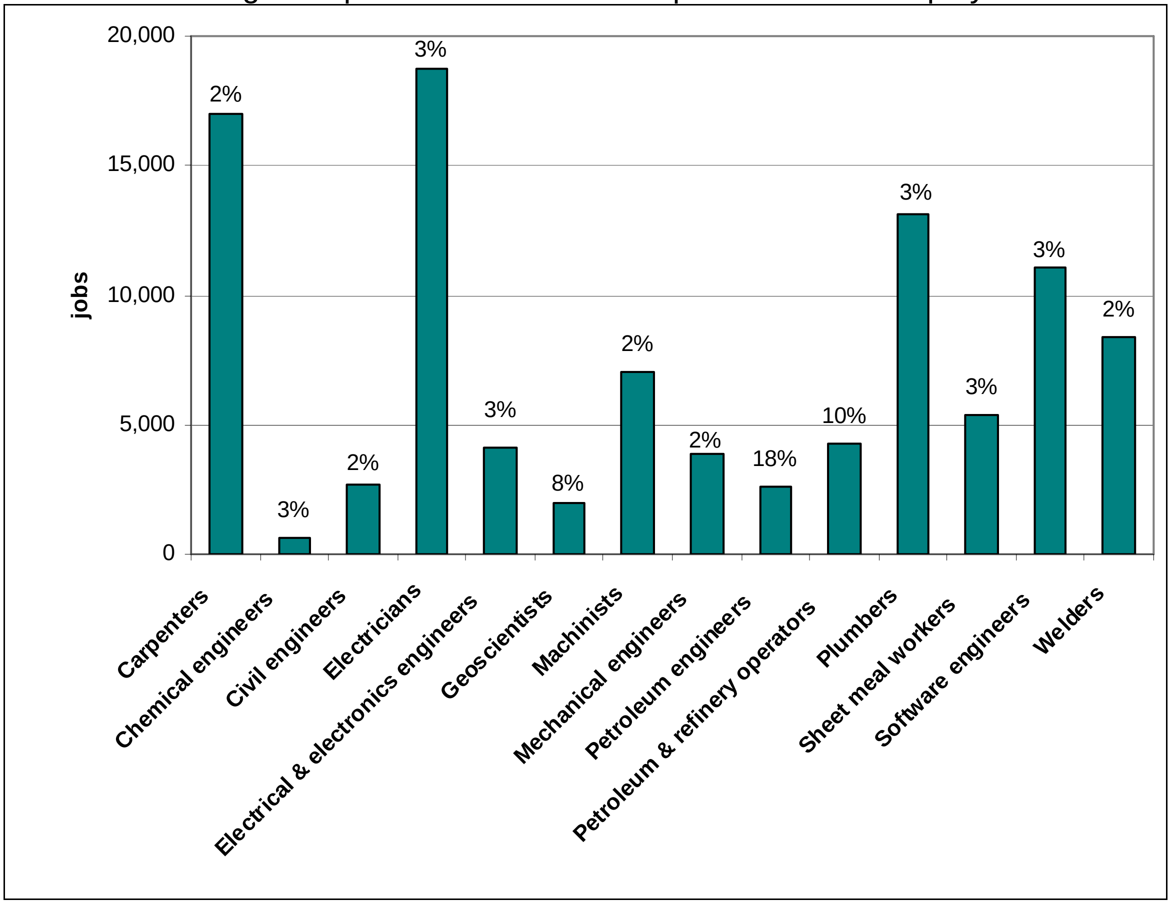
Thus, many workers will be dependent on the mitigation initiatives for their employment, even though they may not be aware of it.

The jobs generated are concentrated in fields related to the construction, energy, and industrial sectors, reflecting the requirements of the mitigation options and their supporting industries. Thus, as illustrated in Table X-1 and Figure X-1, disproportionately large numbers of jobs will be generated for certain in some professional, technical, and skilled occupations. These requirements could cause labor shortages in other industries and professional and skilled occupations, such as chemical, mechanical, electronics, petroleum, and industrial engineers, electricians, sheet metal workers, geoscientists, computer software engineers, skilled refinery personnel, tool and die makers, computer controlled machine tool operators, industrial machinery mechanics, plumbers and pipefitters, oil and gas field technicians, machinists, engineering managers, electronics technicians, carpenters, and others.

Figure X-1

Selected Occupational Requirements for the Four Mitigation Options in Year t_0+20

Percentages Represent Demands Compared to 2004 Employment



XI. STATE IMPACTS

From the information developed in this analysis, it is possible to estimate impacts at the more disaggregated state and local levels. A number of the impacts are inherently state-specific while others are more regional in their economic effect. Both are a strong function of unpredictable future decision-making. Accordingly, we are limited as to how locationally specific we can be.

XI.A. Direct State Impacts

We can estimate the direct economic and jobs impacts of a mitigation option in the state in which the facility is located – "state X."[1] For, example, for the CTL option, the upper bounds on direct impacts are illustrated in Table XI-1. This table shows that there will be substantial economic and employment impacts in the particular state in which the CTL plant is constructed. If more than one CTL plant is constructed in the state, the impacts are roughly scalable.

Table XI-1
Upper Bound Direct Impacts of a CTL Plant in State X

Category	Impact	Occurrence
Development and Construction Expenditures	$7.0 billion	Partial
O&M Expenditures	$350 million	Per year
Coal Feedstock Expenditures	$260 million	Per year
Development and Construction Jobs (direct)	6,000	Per first four years
O&M Jobs (direct)	500	Per year after opening
Development and Construction Payroll (direct)	$252 million	Per first four years
O&M Payroll (direct)	$26 million	Per year after opening
Expenditure, Job, and Payroll Multiplier	1.8-2.2	Every direct dollar and job
Industry Profits	$25 million	National average per year
State and Local Government Income, Sales, Property, and Corporate Tax Revenue	$45-$65 million*	Average per year

*Depends on the individual state and local government tax coverage, structure, and rates.

XI.B. Total Impacts by State

We can also estimate the total (direct plus indirect impacts) in each state generated by mitigation facilities construction and O&M.[2] These are illustrated for year t_0+20 for the major states likely to be impacted for each of the four mitigation options in Tables XI-2 through XI-5. Note that the impacts of the options differ considerably among the states, and the major beneficiaries are larger states, such as California, New York, and Texas; states with the most developed industrial infrastructure, such as Ohio,

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[1]The impacts of the three liquid fuel production options – CTL, oil shale, and EOR – will be state-specific. The impacts of the VFE option will be more widely dispersed among the states.

[2]Assuming that construction of three CTL plants per year are initiated beginning in t_0 and that each plant requires four years to build.

Illinois, and Michigan; and the states where the resources are located, such as Louisiana, Kentucky, and Colorado.

Table XI-2
Top 15 States Affected in Year t_0+20 by the Vehicle Fuel Efficiency Programs – Ranked by Sales

State	**Sales Impact** (billions of 2004 dollars)	**Jobs Impact** (thousands)
Michigan	$9.7	24
California	6.4	32
Ohio	6.0	20
Texas	5.1	21
Indiana	4.3	15
New York	3.5	16
Illinois	3.3	15
Pennsylvania	2.7	13
Kentucky	2.1	7
Tennessee	2.0	9
North Carolina	2.0	9
Georgia	1.9	9
Florida	1.8	13
New Jersey	1.7	7
Missouri	1.6	7
Total, all states	$74	311

Thus, if state policy-makers wished to estimate the overall impacts on their particular state of, for example, the CTL option, they could:

- Use the data in Table XI-1 to estimate the upper bound impact of siting one CTL plant in the state.
- Use the data in Table XI-1 to estimate the upper bound impact of siting multiple CTL plants in the state; e.g., a rough approximation of the impact of siting three plants in the state could be obtained by multiplying the estimates in Table XI-1 by three.
- Use the data in Table XI-3 to estimate the indirect upper bound impacts in their state of the 48 plants sited in all states in t_0+20.
- Use the data in Tables XI-1 and XI-3 to estimate the total upper bound impact in the state of plants sited in the state and those sited in other states.

Table XI-3
Top 15 States Affected in Year t_0+20 by the CTL Option – Ranked by Sales

State	**Sales Impact** (billions of 2004 dollars)	**Jobs Impact** (thousands)
Texas	$12.4	43
California	12.2	53
Illinois	4.8	21
New York	4.8	24
Pennsylvania	4.2	21
Florida	3.7	26
Ohio	3.7	19
Louisiana	3.2	9
New Jersey	3.1	12
Michigan	2.7	15
Georgia	2.6	14
Indiana	2.5	12
North Carolina	2.3	14
Virginia	2.3	13
Kentucky	2.0	10
Total, all states	$101	491

XI.C. Complexity of Generic State Analyses

In reality, there is no such thing as a typical or “generic state.” For example, in principle, a CTL plant can be located in virtually any state, and for the CTL mitigation option there are at least four “generic” categories of states:

- First, the plant may be located in a state in which there are no coal resources and little industrial base – a state such as Mississippi, Florida, Vermont, or Oregon. Call this type of state “Generic State A.”
- Second, the plant may be located in a state in which there are coal reserves but relatively little industrial base – a state such as Wyoming, Utah, or Montana. Call this state “Generic State B.”
- Third, the plant may be located in a state in which there are no coal reserves but a relatively strong industrial base – a state such as New York, Connecticut, or Wisconsin. Call this state “Generic State C.”
- Fourth, the plant may be located in a state in which there are both coal reserves and a relatively strong industrial base – a state such as Illinois, Indiana, or Ohio. Call this state “Generic State D.”

Table XI-4
Top 15 States Affected in Year t_0+20 by the Oil Shale Option – Ranked by Sales

State	**Sales Impact** (billions of 2004 dollars)	**Jobs Impact** (thousands)
Texas	$14.3	38
California	9.9	39
Louisiana	4.0	7
New York	3.4	17
Illinois	3.3	15
Pennsylvania	2.7	14
Ohio	2.5	14
Florida	2.5	19
New Jersey	2.2	9
Michigan	2.0	11
Georgia	1.6	10
Indiana	1.6	8
North Carolina	1.6	10
Virginia	1.4	9
Oklahoma	1.4	7
Total, all states	$78	350

The impacts in the state of the CTL plant will differ critically depending on its categorization according to the above criteria:

- First, if the CTL plant is located in a Generic State A, then the impacts will be limited to those resulting solely from plant construction and operations.
- Second, if the CTL plant is located in a Generic State B, then the impacts will include those resulting from plant construction and operations as well as from production of the required coal feedstock.
- Third, if the CTL plant is located in a Generic State C, then the impacts will include those resulting from plant construction and operations as well as from production of some of the industrial goods and services required for the plant.

Table XI-5
Top 15 States Affected in Year t_0+20 by the EOR Option – Ranked by Sales

State	**Sales Impact** (billions of 2004 dollars)	**Jobs Impact** (thousands)
Texas	$14.5	32
California	7.4	25
Louisiana	4.3	5
New York	2.4	11
Illinois	2.2	10
Alaska	2.0	1
Pennsylvania	1.9	9
Ohio	1.7	9
Florida	1.5	12
New Jersey	1.5	6
Oklahoma	1.5	7
Michigan	1.4	7
Colorado	1.0	5
Indiana	1.0	5
North Carolina	1.0	6
Total, all states	$61	234

- Fourth, if the CTL plant is located in a Generic State D, then the impacts will be the sum of those resulting from plant construction and operations, those resulting from production of some of the industrial goods and services required for the plant, and those resulting from production of the required coal feedstock.

XI.D. Generic States for the Mitigation Options

For the other two substitute fuel options the analysis is similar, but more bounded:

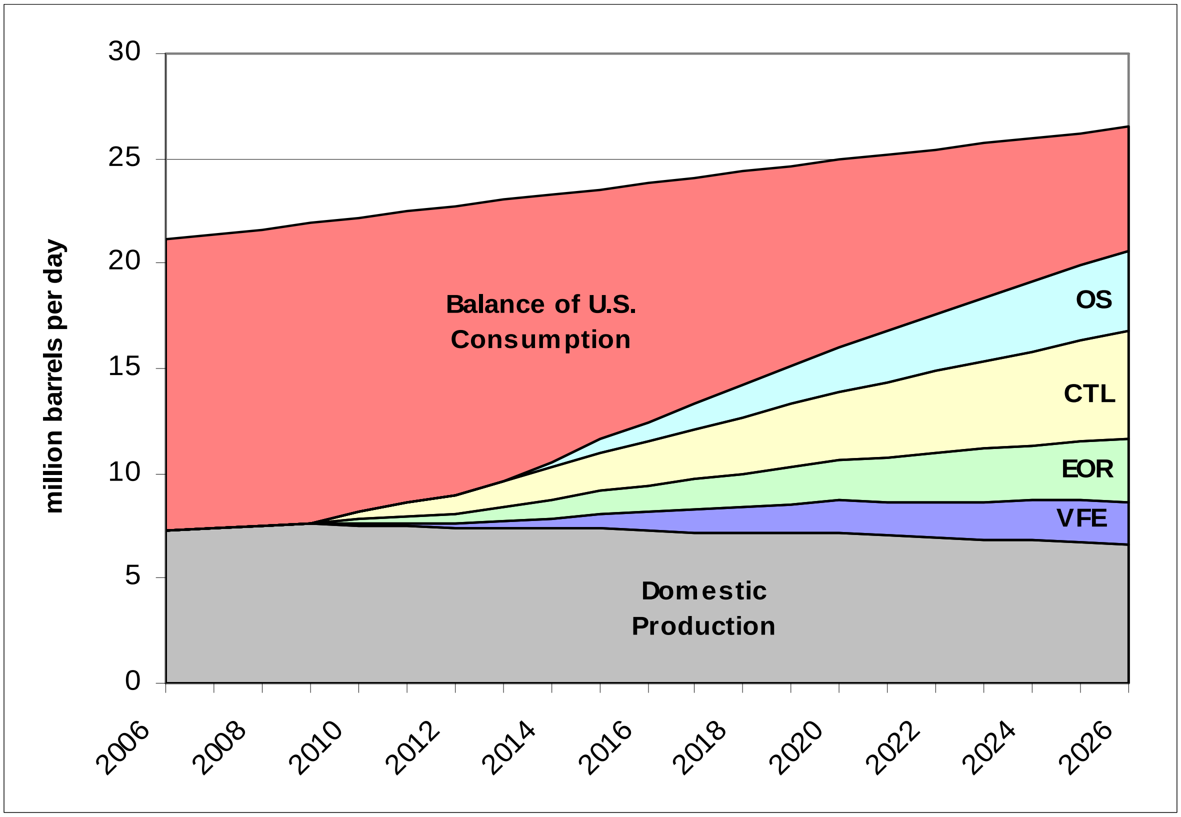
- For the oil shale option, there are three primary candidate states – Colorado, Utah, and Wyoming, and they are all Generic B States: They have large oil shale resources, but relatively little industrial base.
- For the EOR option, there are maybe eight or ten candidate states, and most of them are Generic B States: They have oil, but relatively little industrial base.

No generic state option is necessary for the VFE option. The impact on all 50 states of this option was estimated using methodology described in Chapters IV and V.

XII. ALTERNATIVE INITIATION DATES

It is clear that undertaking mitigation on the scale indicated herein will be a massive undertaking. It is also clear that future impacts will depend critically on the date that such a national effort is initiated. Even with the most optimistic assumptions and crash program implementation, mitigation programs will require decades to make substantial liquid fuel contributions on a national scale. For example, if the efforts described herein were initiated in 2006, the cumulative U.S. impact in 2026 would be roughly 15 million barrels per day, as illustrated in Figure XII-1. If program initiation were delayed until 2011, for example, the impact in 2026 would be roughly 10 million barrels per day (Figure XII-2). Lastly, if program initiation was to start in 2016, the 2026 impact would be only about 5 million barrels per day (Figure XII-3). In each graph, the upper curve represents EIA projected demand for the U.S.[1]

Figure XII-1. Mitigation Impacts if Initiated in 2006



[1] U.S. Energy Administration, Annual Energy Outlook, 2006, February 2006.

Figure XII-2. Mitigation Impacts if Initiated in 2011.

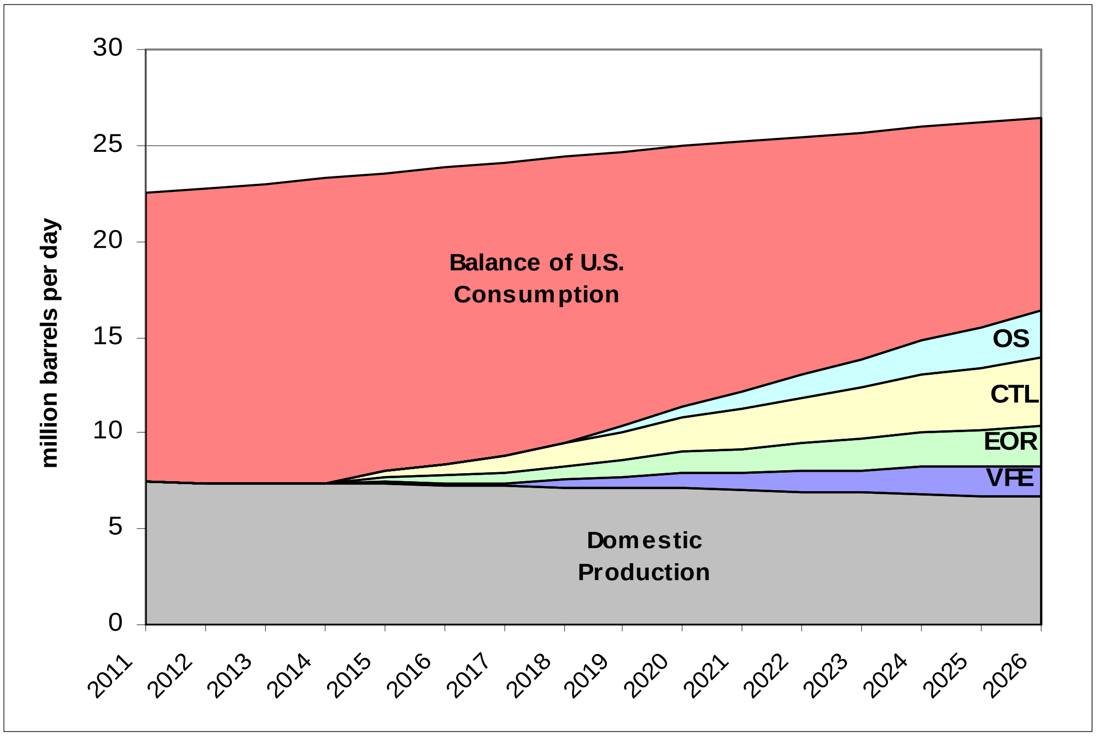
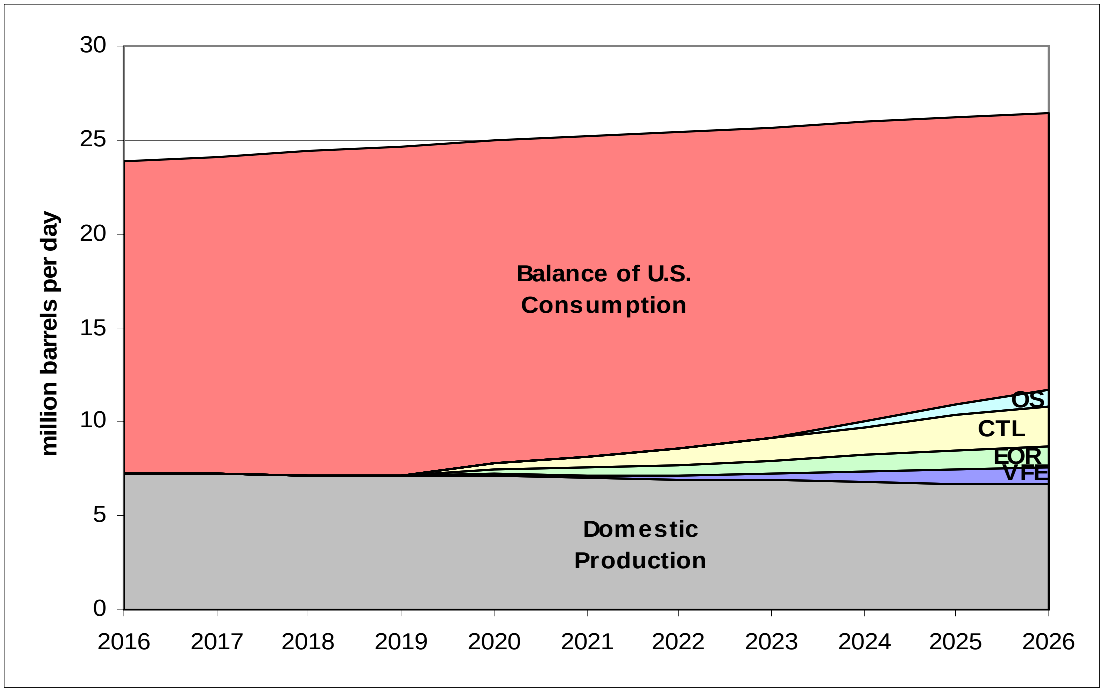


Figure XII-3. Mitigation Impacts if Initiated in 2016



Specifically, Figure XII-1 illustrates the contributions of each mitigation option over the next two decades relative to forecast U.S. liquid fuel consumption, assuming that crash program implementation begins immediately – in 2006. It indicates that:

- Substantial contributions from the options will not begin until after 2010.
- By 2020, the options combined account for about 9 MM bpd of liquid fuels out of a U.S. total liquid fuels consumption of just over 25 MM bpd (about 35 percent)
- By 2026, the options combined account for about 14 MM bpd of liquid fuels out of a U.S. total liquid fuels consumption of about 27 MM bpd (just over 50 percent)

Figure XII-2 illustrates the contributions of each mitigation option over the next two decades relative to forecast U.S. liquid fuel consumption, assuming that crash program implementation does not begin until 2011. It indicates that:

- Substantial contributions from the options will not begin until about 2016 or 2017
- By 2020, the options combined account for about just over 4 MM bpd of liquid fuels out of a U.S. total liquid fuels consumption of just over 25 MM bpd (about 16 percent)
- By 2026, the options combined account for about 10 MM bpd of liquid fuels out of a U.S. total liquid fuels consumption of about 27 MM bpd (about 37 percent)

Figure XII-3 illustrates the contributions of each mitigation option over the next two decades relative to forecast U.S. liquid fuel consumption, assuming that crash program implementation does not begin until 2016. It indicates that:

- Substantial contributions from the options will not begin until about 2021 or 2022
- By 2020, the options combined account for about 0.6 MM bpd of liquid fuels out of a U.S. total liquid fuels consumption of just over 25 MM bpd (about 2 percent)
- By 2026, the options combined account for about 5 MM bpd of liquid fuels out of a U.S. total liquid fuels consumption of about 27 MM bpd (about 19 percent)

XIII. SUMMARY

In the previous chapters we identified and analyzed the potential contributions of four physical mitigation options that the U.S. might undertake in a crash program effort to dramatically reduce its dependence on foreign oil[1]:

1. Vehicle fuel efficiency programs,
2. Coal liquefaction,
3. Oil shale, and
4. Enhanced oil recovery.

All options require a set-up or startup time before they can begin to contribute:

- Fuel savings from the vehicle fuel efficiency will not begin to impact on a significant scale until year t_0+6, because of the time required to retool factories to produce more fuel-efficient vehicles.

- On the production side:
  - For Coal-To-Liquids (CTL) we assumed four years from decision to build to initial operation. (t_0+4).
  - Liquid fuels from oil shale requires time to build dedicated electric power plants, to heat the shale oil in-situ (t_0+4), and then time to heat the rock before oil begins to flow, assumed to occur at t_0+8.
  - Enhanced Oil Recovery (EOR) requires time to drill new wells and to supply carbon dioxide to the fields, assumed to occur at t_0+4.

We implicitly assumed that governments would facilitate these efforts through some combination of expedited permitting, flexible environmental enforcement, financial incentives and subsidies, loan guarantees, etc. Just how such efforts would be formulated and carried out is beyond the scope of this analysis and merits careful study.

The aggregate impacts of the four mitigation options are summarized in Tables XIII-1, XIII-2, and XIII-3 and Figures XIII-1, XIII-2, XIII-3, and XIII-4.

[1]We term these "physical" mitigation options because they are designed to either save or produce large quantities of liquid fuels and will require massive, continuing capital costs, investments, and consumer expenditures. We distinguish these from more strictly policy-oriented options -- such as the 55 mph speed limit or odd/even gas station days.

Table XIII-1
Summary of the Mitigation Option Impacts

Year t_0 + 10						
	Liquid Fuels Production/Savings (MM bpd)	Industry Sales (billions)	Jobs (thousands)	Profits (billions)	Federal Tax Revenues (billions)	S&L Tax Revenues (billions)
VFE*	0.225	$100	500	$4	$21	$11
CTL	2	$65	350	$3	$13	$7
Oil Shale	1	$50	280	$2.5	$10	$5
EOR	1	$30	130	$1.5	$6	$3
Year t_0 + 20						
	Liquid Fuels Production/Savings (MM bpd)	Industry Sales (billions)	Jobs (thousands)	Profits (billions)	Federal Tax Revenues (billions)	S&L Tax Revenues (billions)
VFE	2	$75	300	$3	$15	$7
CTL	5	$100	500	$5	$20	$10
Oil Shale	4	$80	350	$4	$15	$8
EOR	3	$60	235	$3	$6	$3

* The t+10 results for VFE above are for year t+6, the peak year of the national economic impact.

Table XIII-2
Summary of Petroleum Supply, Costs, and Impacts in Year t_0 + 10

	Petroleum Supply/Savings	Direct Costs	Total Impacts		Employment per Million Direct Dollar ('04)
			Sales	Employment	
	(MM bpd)	(b$-'04)	(b$-'04)	(thousands)	
VFE*	0.9	62	107	498	8.0
CTL	2.1	34	65	338	9.9
Oil Shale	0.9	29	51	281	9.7
EOR	1.2	17	31	127	7.5

* The t+10 results listed are for year t+6, the peak year of the national economic impact.

Table XIII-3
Summary of Petroleum Supply, Costs, and Impacts in Year t_0 + 20

	Petroleum Supply/Savings (MM bpd)	Direct Costs (b$-'04)	Total Impacts Sales (b$-'04)	Total Impacts Employment (thousands)	Employment per Million Direct Dollar ('04)
VFE*	2.0	43	74	311	7.2
CTL	5.1	52	101	491	9.4
Oil Shale	3.9	44	78	350	8.0
EOR	3.0	34	61	234	6.9

Figure XIII-1
Total Liquid Fuel Impacts

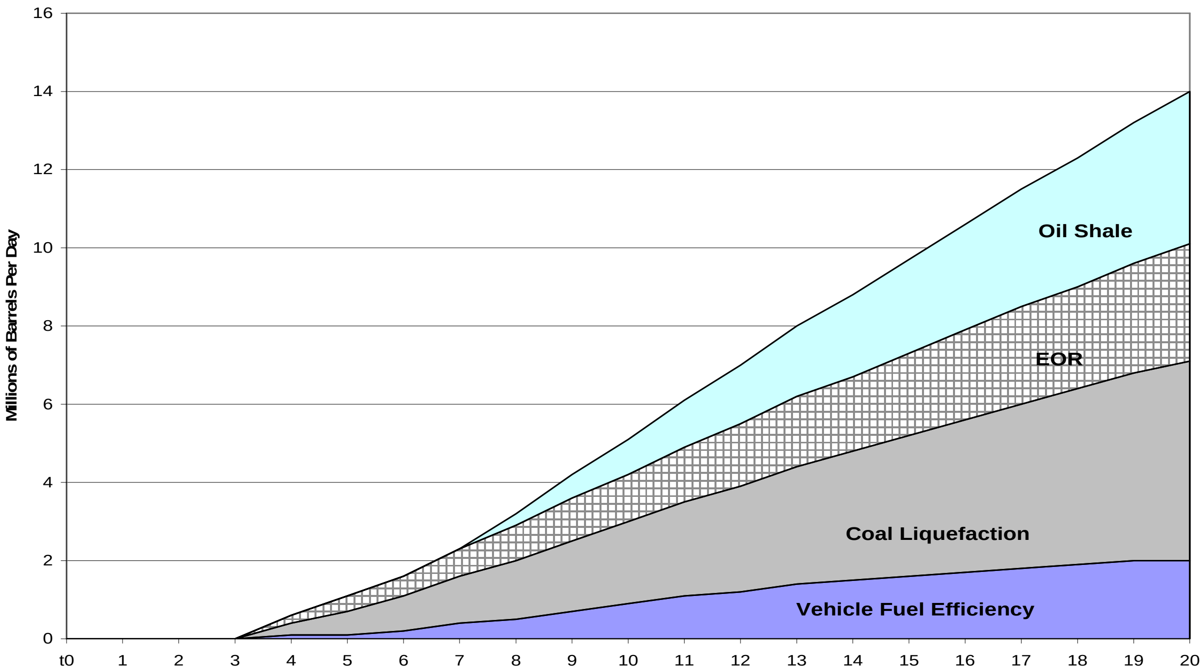


Figure XIII-2
Liquid Fuels Saved and Produced in Year t_0+20

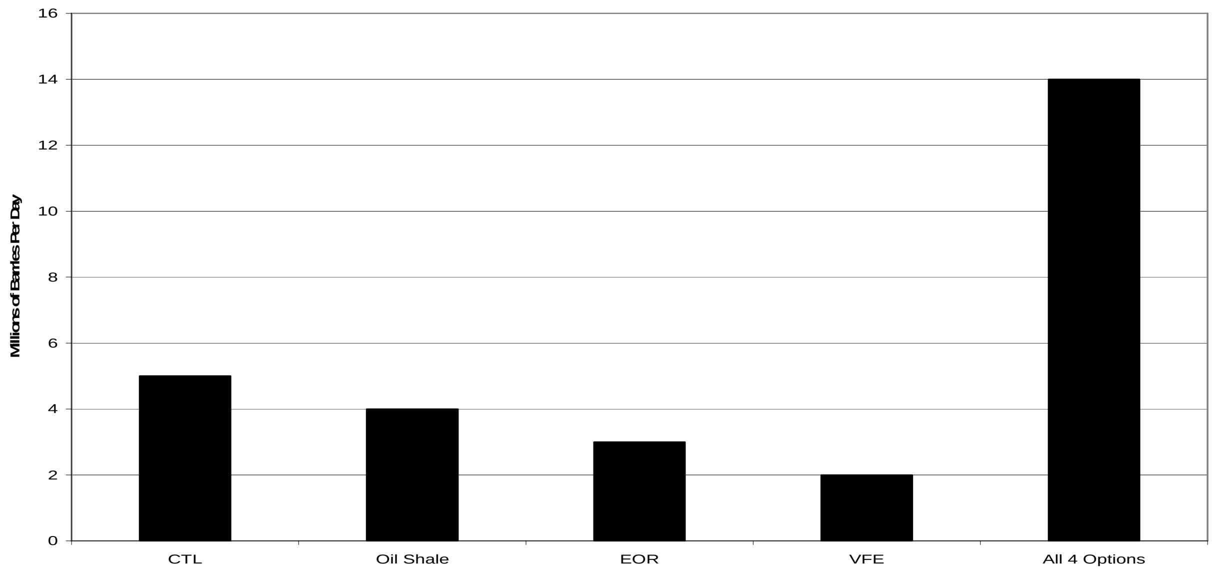


Figure XIII-3
Jobs Created in Year t_0+20

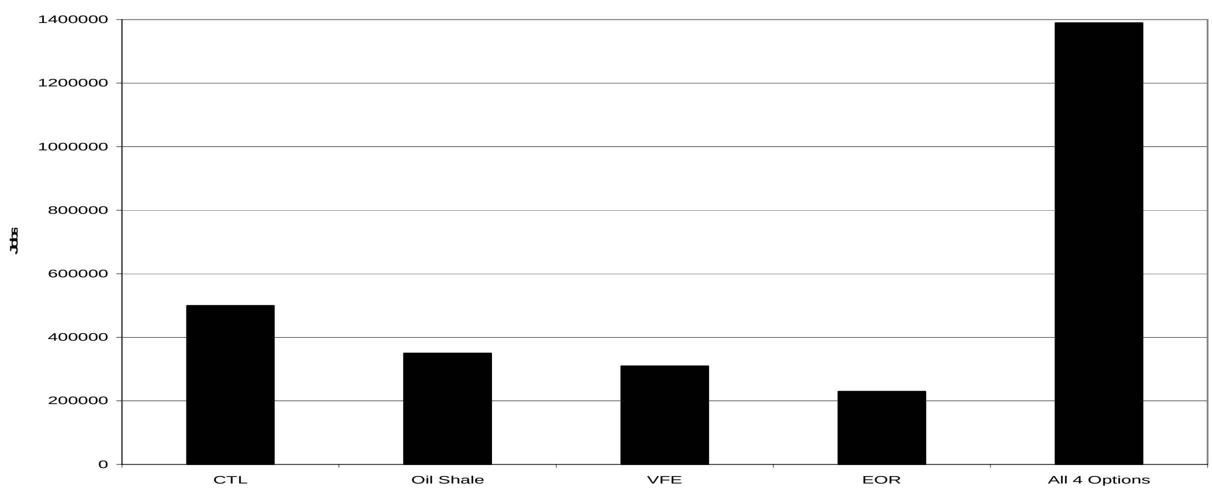
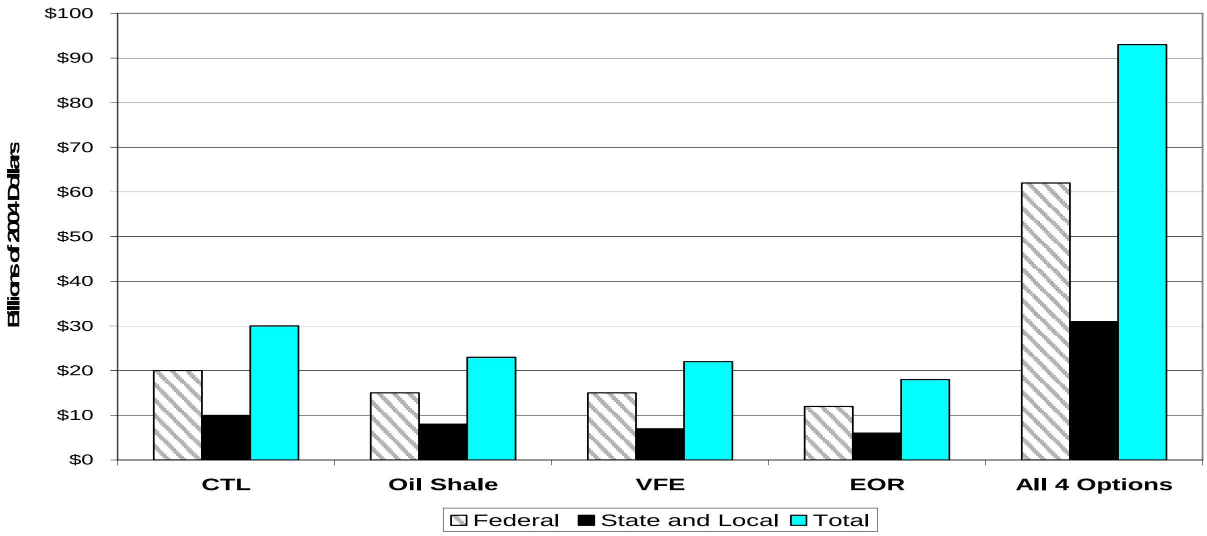


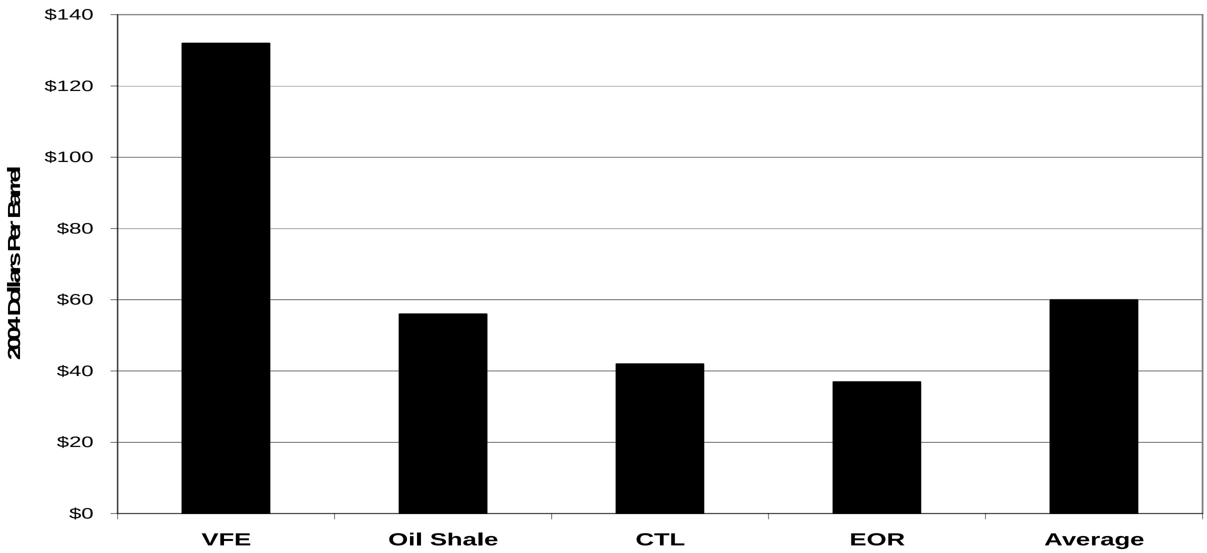
Figure XIII-4
Tax Revenues Generated in Year t_0+20



Cumulatively, over the entire 20 year period through year t_0+4, the average cost of a barrel of fuel saved or produced for all of the options is about $60. However, the cost of each option differs considerably, as illustrated in Figure XIII-5. As illustrated, contrary to conventional wisdom and to some published studies, transportation efficiency may not be the most effective mitigation option,[1] However, the cost estimates for the supply options – especially oil shale and CTL – are subject to a high degree of uncertainty, whereas the cost estimates for the VFE option are likely more accurate. In addition, we truncated our analysis at year t_0+20, and the more fuel efficient vehicles produced will continue to save liquid fuels for about another 15 years. Further, we assumed that there would be no further vehicle fuel efficiency improvements after year t_0+8, which may not be a realistic assumption.

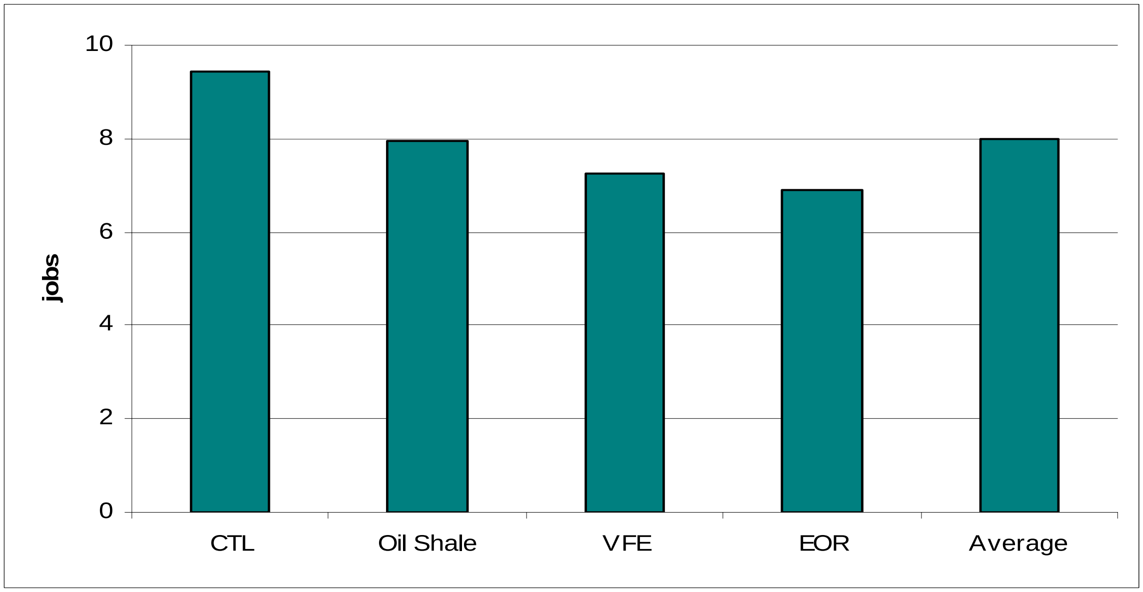
[1]See, for example, National Research Council, National Academy of Sciences. *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*. Washington, D.C.: National Academy Press, 2002; John DeCicco, Feng An, and Marc Ross, *Technical Options for Improving the Fuel Economy of U.S. Cars and Light Trucks by 2010-2015*, American Council for an Energy Efficient Economy, July 2001; Union of Concerned Scientists, *Drilling in Detroit: Tapping Automaker Ingenuity to Build Safe and Efficient Automobiles*, UCS Publications, Cambridge, MA, June 2001.

Figure XIII-5
Relative Costs of the Mitigation Options



The mitigation options can be evaluated on the basis of different criteria. As illustrated in Figure EX-8, on the basis of jobs created per dollar of direct investment, the impacts of the mitigation options differ relatively little: The average is about eight jobs per $1 million invested, with CTL creating the most jobs per dollar of expenditure and EOR the least.

Figure XIII-6
Total Employment Impact per $1 Million of Direct Costs



The economy and labor markets will benefit greatly from the stimulus provided by this crash mitigation program. The following industries will be among the major beneficiaries in terms of sales, profits, and jobs created:

- Oil and gas extraction
- Construction
- Petroleum and coal products
- Professional, scientific, and technical services
- Mining
- Chemical products
- Fabricated metal products
- Pipeline transportation
- Administrative and support services
- Truck transportation
- Primary metals
- Machinery
- Utilities
- Nonmetallic mineral products
- Motor vehicles
- Computers and electronic products
- Plastics and rubber products

XIV. CONCLUSIONS

For decades the world has been consuming more oil than it has been finding, diminishing the earth's endowment of conventional oil. At some point, world production of conventional oil will reach a maximum and begin to decline; production will peak. No one knows when peaking will occur because much of the data needed for an accurate forecast is not assessable. Competent analysts differ on when peaking will occur, but the range covers very soon to 2030.

Beyond the issue of peaking, many people have long been concerned about U.S. dependence on foreign oil imports from both an energy security and a balance of payments standpoint. Indeed, in his 2006 State of the Union Address, President Bush stated that the U.S. is "addicted to oil," and he articulated a goal of reducing U.S. oil imports from the Middle East by 75 percent by 2025. Consideration of this initiative is just now beginning, and the outcome, including the level and timing of such an effort, is yet to be determined.

This study builds on one completed by the authors in 2005 which addressed the issue of world oil peaking.[1] The current study deals exclusively with physical mitigation options for the U.S. The options analyzed in both studies are consistent and are shown in Table XIV-1.

Table XIV-1
Implementation Assumptions

Mitigation Technology	Assumption for the World in the Previous Study	Assumptions for the U.S. in This Study
Vehicle fuel efficiency	Ramping up to a 50% increase in vehicle fuel efficiency after 8 years	Ramping up to a 50% increase in vehicle fuel efficiency after 8 years
Coal-to-liquids	5 new 100,000 bpd plants/yr. 4 years to build	3 new 100,000 bpd plants/yr. 4 years to build
Enhanced oil recovery	World oil production increased by 3 MM bpd after 10 years	175,000 bpd added each year after 4 years construction
Oil sands/heavy oil	2.5 MM bpd of incremental production achieved 13 years from a decision to accelerate	None
Gas-to-liquids	1 MM bpd achieved in 5 years	None
Oil shale	None	3 new 100,000 bpd plants/yr. 8 year delay

Crash program implementation of all options simultaneously was considered, because related results provide an upper limit on what might be accomplished under the best of circumstances with technologies that are now either commercial or near commercial. Using available technical, cost, employment, tax, and other data, along with a number of simplifying assumptions, we developed rough estimates of a range of

[1]Hirsch, Bezdek, and Wendling, op.cit.

potential implications of undertaking such an ambitious program. Because no one knows if and when such a program might be undertaken, we performed our calculations based on an unspecified starting date, designated as t_0.

Cumulative Impacts

Our estimates indicate that the cumulative 20 year impact (through year t_0+20) of such a massive crash program would be:[1]

- Savings and production of 44 billion barrels of liquid fuels
- An accumulated investment of $2.6 trillion[2]
- Over 10 million employment years of jobs will have been created
- Total industry sales of over $3 trillion would have occurred over the period
- Over $125 billion of industry profits would have accumulated
- Over $500 billion in federal government tax revenues will have accumulated
- Nearly $300 billion in state and local government tax revenues would have accumulated

Impacts in Year t_0+20

Oil saving and liquid fuel production from each of the programs in year t_0+20 would be as follows:

- 5 MM bpd of coal liquids
- 4 MM bpd of liquid fuels from shale oil
- 3 MM bpd of oil from EOR
- 2 MM bpd of liquid fuel savings from vehicle fuel efficiency

In terms of employment generated in year t_0+20:

- CTL creates the most jobs – about 500,000
- Oil shale creates 350,000 jobs
- VFE creates 310,000 jobs

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[1]In addition to the impacts identified here, there are other significant potential secondary economic impacts that are likely to result. These include the impact on the U.S. balance of trade, impact of lower imports, economic impacts of environmental actions as a result of the mitigation schemes, and infrastructure impacts such as housing, pipelines, roads, etc.

[2]Actual costs will likely be much higher because our calculations were based on nth plant cost estimates. They did not take into account the large cost escalations certain to occur after program initiation, when demand for goods and services vastly outstrip supplies. Similar considerations would likely apply to estimates of jobs and other revenues. Note that $2.6 trillion in cumulative costs over 20 years comprises less than one percent of likely cumulative GDP over the next two decades and about four percent of cumulative direct investment over this period. Additional perspectives are provided in Appendix C.

- EOR creates the least number of jobs – about 230,000

The economic activity stimulated and the jobs created will generate substantial tax revenues for the federal, state, and local governments. In year t_0+20:

- CTL will generate $30 billion in tax revenues
- Oil Shale will generate $23 billion in tax revenues
- VFE will generate $22 billion in tax revenues
- EOR will generate $18 billion in tax revenues
- The four mitigation options combined will generate $93 billion in tax revenues

It is important to note that the impacts will increase continuously over the 20 year scenario period. Thus, relatively small numbers of fuel savings and production, sales, jobs, profits, and tax revenues will be generated in the early years, but the impacts will increase every year through year t_0+20. For all of the mitigation options combined, the maximum annual impacts occur in t_0+20.

The results pertaining to the impact on the U.S. economy and employment are particularly interesting. Large investments and efforts need to be undertaken to produce domestic replacements for imported oil, and mitigation initiatives to lower demand for imports, involving massive spending, will lead to large numbers of domestic U.S. jobs and large profits for the producers. Given the inevitable necessity of mitigating the conventional oil shortage, the creation of new employment opportunities in technical and manufacturing areas is a key finding resulting from the analysis. This move of "manufacturing" into the United States instead of importing a non-manufactured "mined" imported hydrocarbon will result in many new jobs and other positive consequences. Such a transition also leverages U.S. natural resources and will substantially improve the U.S. balance of payments.

Transportation Efficiency Programs

In the course of this work, we found one unexpected result. Contrary to conventional wisdom and to some published studies, transportation efficiency may not be the most effective mitigation option, However, the cost estimates for the supply options – especially oil shale and CTL – are subject to a high degree of uncertainty, whereas the cost estimates for the VFE option are likely more accurate. In addition, our analysis was truncated at year t_0+20, and more fuel efficient vehicles produced will continue to save liquid fuels for their lifetimes, another 15 years or more. Further, we assumed that there would be no further vehicle fuel efficiency improvements after year t_0+8, which may be a limiting assumption.

Potential Downside Risks

There may be potential downside risks involved in initiating the types of large mitigation initiatives assessed here. Could a portion of the money and effort be wasted? Some of the major assumptions made (such as, for example, the future price and price volatility of oil) could, at least in the short term, be invalid. Will the large projects modeled here have long, economic lives or will better technologies make them prematurely obsolete? Are better technologies possible? If oil peaking is delayed, will the initiatives be premature and costly? Conversely, might some of them be implemented too late? These and related issues are serious and must be carefully evaluate.

More generally, the peaking of world conventional oil production presents a classic risk management problem:

- Mitigation efforts initiated earlier than required may turn out to be premature, if peaking is long delayed.
- On the other hand, if peaking is imminent, failure to initiate timely mitigation could be extremely damaging.

However, the salient point is that the two risks are asymmetric:

- Mitigation actions initiated prematurely will be costly and could result in a sub-optimal use of resources.
- On the other hand, delayed or late initiation of mitigation may result in very severe energy, economic, and social consequences.

Prudent risk management requires the planning and implementation of mitigation well before peaking. Early mitigation will almost certainly be less expensive and less damaging to the world's economies than delayed mitigation.

The world has never confronted a problem like this, and the failure to act on a timely basis could have debilitating impacts on the world economy. Risk minimization requires the implementation of mitigation measures well prior to peaking. Since it is uncertain when peaking will occur, the challenge is indeed significant.

Reduction of U.S. Oil Imports

In terms of reducing U.S. oil imports, if the crash mitigation programs were initiated in 2006, it appears possible to begin to noticeably reduce U.S. oil imports by about 2010. In fact, the total level of U.S. imports would be reduced to roughly 12 MM bpd in 2016 and 6 MM bpd in 2026.

If crash program implementation is delayed ten years (2016), then by 2026 these mitigation options may contribute about 5 MM bpd, but U.S. imports would still rise to about 15 MM bpd.

In summary, based on our optimistic assumptions and immediate crash program implementation, it will require well over a decade and trillions of dollars of investment for the mitigation options to account for a substantial portion of U.S. liquid fuel consumption. A long period of delay before such a program is initiated will mean that oil import demands may not be alleviated until the 2030s, by which time world oil peaking will likely have occurred.

Examination of our findings indicates that all of the physical mitigation options will be needed if the U.S. is to address its liquid fuels problem within the next two decades. Even then it will be difficult to satisfy even half of the U.S. liquid fuels requirements prior to 2025.

Our analysis indicates the approximate magnitudes of the activities and benefits associated with a massive program to reduce U.S. dependence on foreign oil. Such an undertaking would be unprecedented. Justifications include mitigation of world peaking of conventional oil production, national security, and balance of payments reduction.

The reason why such an effort will be required is abundantly clear: The scale of U.S. oil consumption is enormous and making massive changes will require an enormous, expensive, crash program effort and at least two decades. Fortunately, the U.S. is endowed with needed geological resources, capital, labor, and management to undertake such an effort.

APPENDIX A
EXAMPLES OF PREVIOUS STUDIES UTILIZING THE MISI MODELING APPROACH

The methodology employed in this study has been refined and used by MISI for three decades in a variety of studies of energy and environmental projects, economic initiatives, proposed legislation, government programs, etc. Examples are given below.

Vehicle Fuel Efficiency Programs

Roger Bezdek and Robert Wendling. "Fuel Efficiency and the Economy." *American Scientist*, Volume 93 (March-April 2005), pp. 132-139.

Roger Bezdek and Robert Wendling. "Potential Long-term Impacts of Changes in U.S. Vehicle Fuel Efficiency Standards." *Energy Policy*, Vol. 33, No. 3 (February 2005), pp. 407-419.

Management Information Services, Inc. and 20/20 Vision. *Fuel Standards and Jobs: Economic, Employment, Energy, and Environmental Impacts of Increased CAFE Standards Through 2020*. Report prepared for the Energy Foundation, San Francisco, California, July 2002.

Energy and Technology Programs

Management Information Services, Inc. *The American Energy Security Study: Building a Bridge to Energy Independence and a Sustainable Energy Future*. Prepared for the Southern States Energy Board, Norcross, Georgia, July 2006.

Roger Bezdek and Robert Wendling. "Nuclear Energy Facilities: What Impact do They Have on Property Values and Other Factors in Nearby Communities?" The *International Journal of Nuclear Governance, Economy and Ecology,* Vol.1, No. 1, (2006), pp. 122-144.

Roger Bezdek. "Refusing to Repeat Past Mistakes." Chapter 8, pp. 93-101, in *Climate Change and Economic Growth: A Way Forward to Ensure Both*, edited by Margo Thorning and Andrei Illarionov, published jointly by the International Council for Capital Formation (Brussels and Washington, D.C.), the Institute of Economic Analysis (Moscow), and the Instituto Bruno Leoni (Turin, Italy), February 2005.

Roger Bezdek and Robert Wendling. "A Half Century of Long-Range Energy Forecasts: Errors Made, Lessons Learned, and Implications For Forecasting." *Journal of Fusion Energy*, Vol. 21. No. 3/4 (December 2003), pp. 155-172.

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Roger Bezdek and Robert Wendling. "Impact of the Space Program on the U.S. Economy: National and State Analyses." *Space Power*, Vol. 11, No. 1 (1992), pp. 43-65.

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Roger Bezdek and Robert Wendling. "Costs and Results of Federal Incentives for Commercial Nuclear Energy." *Energy Systems and Policy*, Vol. 15, 1991, pp. 269-293.

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Environmental Programs

Roger Bezdek and Robert Wendling. "Jobs Creation and Environmental Protection." *Nature*, Vol. 434, No. 7033 (March 31, 2005), p. 678.

Management Information Services, Inc. *Jobs Creation in the Environmental Industry in the United States and Selected States.* Reports prepared for the Jobs and Environment Initiative and the Rockefeller Foundation, the Cummings Foundation, the Merck Fund, and the Beldon Fund, Washington, D.C., 2004 - 2005. Reports available for Arizona, California, Connecticut, Florida, Michigan, Minnesota, North Carolina, Ohio and Wisconsin at www.misi-net.com.

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APPENDIX B
BACKGROUND ON INCREASES IN VEHICLE FUEL EFFICIENCY STANDARDS

Policy Options for Improving Fuel Efficiency

Various options other than vehicle fuel efficiency standards have been proposed for improving transportation fuel efficiency, the most important of which are summarized below.

Gasoline Taxes

Higher gasoline prices resulting from higher taxes will result in a reduction in fuel consumed, with each individual deciding how much less gasoline to purchase. Most studies of the impact of increasing fuel prices through taxes have found that the gasoline price elasticity of demand, the percentage reduction in the quantity of gasoline purchased in response to a percentage increase in gasoline price, is relatively low.[1] This implies that to reduce vehicle fuel consumption significantly, a large increase in gasoline taxes is required, and such a large tax increase is usually considered to be politically unpalatable. In addition, gasoline taxes are regressive and may harmfully impact low income groups the most. Finally, a tax increase to encourage fuel efficiency could adversely impact the economy by reducing demand and output. Although these last two problems could be addressed by a policy that granted offsetting tax relief to ensure that the revenue effect would be neutral[2], the political obstacles to significantly increased gasoline taxes remain formidable.

Proponents of fuel taxes note that, unlike vehicle fuel efficiency standards, increased fuel taxes will affect all vehicle use, whereas an increase in mileage standards would only apply to new vehicles while older and less fuel-efficient vehicles would remain on the road for years. Fuel taxes would also not be subject to the "rebound" effect.[3] Finally, proponents of increasing the gasoline tax also argue that the marginal cost of motor vehicle use is below the marginal social costs that automobiles impose. A fuel tax increase would then serve the dual purpose of reducing petroleum use and reducing the external costs of automobile transportation.[4]

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[1]See Dahl and Sterner, "Analyzing Gasoline Demand Elasticities: A Survey", *Energy Economics*, v. 13, no. 3, 1991, pp. 203-210.
[2]See Roger H. Bezdek and William Taylor. "Allocating Petroleum Products During Oil Supply Disruptions: A Comparison of Four Alternative Plans," *Science*, Vol. 212, June 19, 1981, pp. 1357-1363.
[3]The rebound effect refers to the possibility that, as CAFE standards make the per-mile cost of driving less expensive, people may tend to drive more.
[4]See, for example, James J. Murphy and Mark A. DeLucchi, "A Review of the Literature on the Social Cost of Motor Vehicle Use in the United States," *Journal of Transportation and Statistics*, January 1998, pp. 15-42. Pollution and congestion are two externalities often cited in connection with vehicle use.

Fees and Rebates

A policy that establishes a program of fees and rebates on new vehicle purchases, depending on whether or not the vehicle attained the mandated mileage standards, has been suggested as a way to use economic incentives to improve fleet fuel economy. Under current U.S. law, a "gas guzzler" tax must be paid on purchases of automobiles that do not meet EPA mileage standards. Since 1991, these taxes have ranged from $1,000 to $7,700, depending on the vehicle's fuel economy, but only the most exotic high-performance imports are subject to the higher fines. The gas-guzzler tax was first imposed in 1981, and the minimum fuel economy threshold at which fines are first applied was raised in steps over the years until it reached 21.5 mpg in 1986. Through the years, U.S. manufacturers managed to improve the gas mileage of their least fuel-efficient automobiles to avoid the tax penalties, and these improvements were made even when the overall fleet fuel efficiency averages of automobiles were not increasing.[1] The gas-guzzler tax currently applies only to automobiles, but the success of this tax in providing domestic manufacturers with the incentive to improve the gas mileage of their least fuel efficient automobiles has led to the proposal that the "gas guzzler" policy be extended to cover light trucks, vans, and SUVs.

This success of the program supports the idea of broadening the policy to include not only penalties on low mileage vehicles, but also rebates on vehicles that attain better-than-average fuel economy. Such a "feebate" program could be revenue neutral, and any taxes collected on gas guzzlers could be rebated to purchasers of more fuel-efficient vehicles. The fees and rebates would give consumers an incentive to purchase more fuel-efficient vehicles, and would give manufacturers the incentive to continuously improve the fuel efficiency of vehicles.[2]

Technology Fixes

Some analysts contend that the current U.S. petroleum-dependent transportation system cannot be fixed with marginal changes around the edges, but that a more radical re-design of the transportation fleet is needed. Accordingly, there are proposals to build radically different vehicles. For example, this was the goal of the "supercar" program under the government-business "Partnership for a New Generation of Vehicles" (PNGV).[3] These vehicles would use new body materials, better streamlining, low-rolling resistance tires, and advanced engines that might run on alternative fuels such as methanol, natural gas, hydrogen fuel cells, electricity, or some combination thereof.[4] While there have been impressive advances in the technology required for

[1]See Marc Ross, Marc Ledbetter, and Feng An, *Options for Reducing Oil Use by Light Vehicles: An Analysis of Technologies and Policy*, ACEE: Washington, December 1991, pages 36 and 92.
[2]See Steve Plotkin, *Technologies and Policies for Controlling Greenhouse Emissions from the U.S. Automobile and Light Truck Fleet*, Center for Transportation Research, Argonne National Laboratory, Argonne, Illinois: January 2000, pp.12-13.
[3]The program was discontinued by the Bush Administration in February 2002 and replaced by the Freedom Car program that emphasizes fuel cell vehicles.
[4]Even low-tech options can increase vehicle fuel efficiency; for example, inflating tires properly can reduce gasoline consumption by as much as two percent.

these vehicles, several important technological and economic hurdles remain before such "supercars" could play a major role in the transportation system.[1] For example, the infrastructure required to provide fueling stations for alternative-fuel vehicles would involve a massive capital outlay.

Proposals also exist to improve transportation efficiency by technological improvements in the way in which roads are used. These are known as Intelligent Vehicle-Highway Systems (IVHS), and include technologies that would create both smart highways and smart cars. The basic idea is to use technology such as radar, video monitoring, highway access controls, and on-board real-time information systems to improve the efficiency with which existing roadways are used. Some studies indicate that road capacities could be increased by 10 to 20 percent when IVHS systems are applied.[2] The problem is that while IVHS may initially reduce travel time, traffic congestion, and vehicle fuel use, the improvements may attract and encourage more driving, and thus offset fuel economies gained by the IVHS.

Transportation Demand Management

There is another broad range of policy options, some of which are currently being utilized, that seek to improve transportation fuel efficiency by changing the basic structure and patterns of personal transportation. These range from efforts to encourage people to use public transportation and to car pool to more basic structural reforms in land use planning and tax policies, as well as public investment in high-speed intercity ground transportation -- such as developing the types of bullet trains found in Europe and Japan. Also included under this broad classification are policies such as congestion pricing of highways, the encouragement of telecommuting, the establishment of high-occupancy vehicle (HOV) lanes, and the institution of parking charges designed to discourage driving, especially by single-occupant vehicles. While these can provide a useful supplement to efforts at fuel conservation, several of them would require drastic changes in national policies that may not be politically viable. However, new public attitudes toward the risk of global oil depletion or the growing dependence on oil imports could change the political equation.[3]

Speed Limit Reduction

In 1973, the federal government mandated the 55-mph speed limit at the request of President Nixon, who proposed it as a way to conserve fuel during the Arab oil embargo. In March 1974, Congress enacted legislation that established a national 55-mph speed limit on the nation's highways. The measure was part of a package of laws

[1]A more radical concept is the "Hypercar," a vehicle designed to capture the synergies of ultralight construction, low-drag design, hybrid-electric drive, and efficient accessories to achieve a 3 to 5-fold increase in fuel economy. See www.rmi.org.
[2]See U.S. Congress, Office of Technology Assessment, *Saving Energy in U.S. Transportation*, OTA-ETI-589, Washington, D.C.: U.S. Government Printing Office, July 1994, pp. 244-247, for a discussion of these issues.
[3]Advocates point to the example of Portland, Oregon, where many transportation demand management ideas have been successfully implemented.

passed in response to the oil crisis, and the original intent was to save oil.[1] States, which had always set the speed limits on their highways, lost that authority.[2] In November 1995, President Clinton signed a transportation bill that ended the Federal 55 mph speed limit and gave that authority back to the states, allowing them to set their own speed limits.

While driving 10 miles an hour above the 55 mph limit can increase fuel consumption by 15 percent, the overall impact of speed limit reductions on vehicle fuel consumption is widely debated. Estimates of the reduction in fuel consumption attributable to reduced speed limits range from 2.2 percent to less than one percent.[3]

History of CAFE

When the Arab oil embargo was imposed in 1973, the fuel efficiency of the average U.S. passenger car was less than 13 miles per gallon (mpg). The Energy Policy and Conservation Act of 1975 instituted a new Corporate Average Fuel Economy (CAFE) program, which required automobile manufacturers to more than double the fuel efficiency of the cars they sold. The increase was phased in over several years: For the 1978 model year, the standard for passenger cars was set at 18 mpg, and it gradually increased to 27.5 mpg by 1985, the current level.

The new regulations had the intended effect. The fuel efficiency of new passenger cars rose rapidly during the late 1970s and reached a plateau in the early ’80s. Around this time, car manufacturers had gotten close enough to the target of 27.5 mpg that they could focus their efforts on improving engine performance. Beginning in 1982, while average fleet mpg leveled off, the average acceleration time from 0 to 60 mph (a measure of performance) began to improve steadily. The manufacturers also used advances in technology to “buy” additional vehicle weight. That is, instead of continuing to increase the mpg of their fleets, they kept the fuel efficiency just above the legal requirement and manufactured larger and faster cars.

Over the past two decades, the average fuel economy for all vehicles has declined, from a peak of 22.1 mpg in 1987 to 21.0 mpg for model year 2005.[4] The reason is a loophole in the CAFE regulations, coupled with a dramatic shift in the tastes of car buyers. The CAFE standards treated “light trucks” differently, and more leniently, than passenger vehicles. Such vehicles were considered to be primarily for commercial

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[1]Even though the original intent was to save oil, most of the controversy over the “double nickel” speed limit concerned whether or not it saved lives.
[2]Before the federally mandated speed limit, states set the limits anywhere from 65 mph to 80 mph, and Montana and Wyoming had no speed limit.
[3]See Jad Maouawad and Simon Romero, “Unmentioned Energy Fix: A 55 M.P.H. Speed Limit,” *New York Times*, May 1, 2005, and Stephen Moore, “Speed Doesn’t Kill: The Repeal of the 55-MPH Speed Limit,” Cato Policy Analysis no. 346, May 31, 1999.
[4]These figures are based on “real world” estimates and are about 15 percent lower than the fuel economy values used by the U.S. Department of Transportation for compliance with the CAFE program. See *Light-Duty Automotive Technology and Fuel Economy Trends: 1975 through 2005*, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, EPA420-R-05-001, July 2005.

use (although even by the late 1970s, two-thirds or more of them served as passenger carriers). Therefore, the CAFE standard for light trucks was set at 20.7 mpg, where it remained.[1]

In 1976, shortly after the passage of the CAFE legislation, sales of light trucks amounted to less than 20 percent of all light vehicle sales. But due to greatly increased sales of sport-utility vehicles in the 1990s, the light truck category -- which includes pickups, minivans, SUVs, mini-SUVs and even certain "crossover" vehicles like the Chrysler PT Cruiser – currently accounts for well over 50 percent of all new sales.[2] Manufacturers have also taken advantage of the strict wording in the law. For example, by simply making the rear seats removable in what most would consider a personal passenger vehicle, a manufacturer can reclassify the vehicle as a light truck, thus exempting it from the stricter standards for passenger cars.

Nevertheless, the original CAFE standards had a significant impact on vehicle fuel economy and gasoline consumption over the past quarter-century. Specifically, CAFE has had significant beneficial effects for consumers, the nation, and the environment, compared to the situation had the standards not been enacted:

- At present, vehicle fuel use is approximately 33 percent lower than if fuel economy had not improved since 1975.
- The U.S. saves 43 billion gallons per year of gasoline (2.8 million barrels per day).
- 2.8 million barrels/day equals about 12 percent of U.S. oil consumption.
- U.S. drivers save about $118 billion annually in fuel costs.[3] This represents, on average, about $500 per vehicle per year.
- U.S. carbon emissions have been reduced by 100 million tons/yr. (seven percent of the U.S. total).
- There is a reduced likelihood of the occurrence and severity of oil market disruptions.

[1]In August 2005, the Bush Administration proposed new rules mandating a small increase in fuel economy standards for minivans, pickup trucks, and sport utility vehicles starting in 2008 and to be phased in by 2011. The new rules -- the first major rewrite of the CAFE standards since they were created -- would replace the current requirement that automakers meet a single average mileage standard for their entire fleet of light trucks with a new system that divides vehicles into six classes based on their size and would establish mpg requirements ranging between 21.3 mpg and 28.4 mpg. The proposed new system would continue to exempt large sport utility vehicles and trucks weighing more than 8,500 pounds -- such as the Hummer H2 and the Ford Excursion -- from the standards because they are considered commercial vehicles, even if they are not used as such.
[2]In 2004, light trucks accounted for 56 percent of new sales.
[3]Based on an average price of $2.75 per gallon.

Technologies Available For Increasing Vehicle Fuel Efficiency

In 2002, the National Research Council published a landmark study of the CAFE standards.[1] The NRC analyzed technical, safety and related aspects of the CAFE requirements and estimated how a variety of feasible technologies would affect vehicle costs. We relied heavily on the NRC report to develop the ambitious but substance-based scenario used here for increasing vehicle fuel efficiency standards.

The NRC found that technologies available for improving vehicle fuel efficiency are continually evolving, and those currently available can be utilized more widely and efficiently and further refined to achieve enhanced fuel economy. In addition, emerging technologies, now in the late stages of development, will likely be introduced over the next several years and will be increasingly utilized, and advanced technologies currently in the R&D stage could become available over the next ten to 15 years.[2] The technical options for improving vehicle efficiency can be classified into two basic categories:

- Powertrain technologies, which include engines, transmissions, and the integrated starter-generator
- Load reduction technologies, which include mass reduction, streamlining, tire efficiency, and accessory improvements

These technologies and their associated costs and potential fuel efficiency improvements are summarized in Table B-1 According to the NRC, these engine, transmission, and vehicle technologies are likely to be available within the next 15 years:[3] Some (listed as "production intent") are already available, are well known to manufacturers and their suppliers, and could be incorporated in vehicles once a decision is made to use them; others (designated "emerging") are generally beyond the R&D phase and are under development, and are sufficiently well understood that they should be available within 10 to 15 years. [4]

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[1]National Research Council, National Academy of Sciences. *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*. Washington, D.C.: National Academy Press, 2002.

[2]A more complete discussion of these technical issues can be found in National Research Council, op. cit.; National Research Council, *Automotive Fuel Economy: How Far Should We Go?* Washington, D.C.: National Academy Press, 1992; John DeCicco and Marc Ross, "Improving Automotive Efficiency," *Scientific American*, December 1994, pp. 52-57; U.S. Office of Technology Assessment, *Advanced Automotive Technology: Visions of a Super-Efficient Family Car*, OTA-ETI-638, September 1995; John DeCicco and Marc Ross, "Recent Advances in Automotive Technology and the Cost-Effectiveness of Fuel Economy Improvement," *Transportation Research*, Vol. 1., No 2 (1996), pp. 79-96; David Greene and John DeCicco, *Engineering-Economic Analyses of Automotive Fuel Economy Potential in the United States*, Oak Ridge National Laboratory, ORNL/TM-2000/26, February 2000; John DeCicco, Feng An, and Marc Ross, *Technical Options for Improving the Fuel Economy of U.S. Cars and Light Trucks by 2010-2015*, American Council for an Energy Efficient Economy, July 2001.

[3]National Research Council, National Academy of Sciences. *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*, op. cit.

[4]For each technology, the NRC identified its likely cost to the consumer and estimated the percentage improvement in fuel economy that it could achieve. All of the technologies come at a price, from as little as $8 for low-friction lubricants (a 1-percent improvement in fuel mileage) up to as much as $560 for a "camless engine" (an emerging technology that would save 5 to 10 percent in fuel mileage).

Table B-1
Potential Increases in Fuel Economy and Related Price Increases

Technology	Potential Fuel Efficiency Improvement	Potential Average Retail Price Increases
Engine Technologies		
Production-Intent Engine Technologies		
Engine friction and other mechanical/hydrodynamic loss reduction	1% - 5%	$35 - $140
Application of advanced, low friction lubricants	1%	8 - 11
Multi-valve, overhead camshaft valve trains	2% - 5%	105-140
Variable valve timing	2% - 3%	35-140
Variable valve lift and timing	1% - 2%	70-210
Cylinder deactivation	3% - 6%	112-252
Engine Accessory Improvement	1% - 2%	84-112
Engine downsizing and supercharging	5% - 7%	350-560
Emerging Engine Technologies		
Camless Valve Actuation	5% - 10%	280-560
Variable Compression Ratio	2% - 6%	210-490
Intake Valve Throttling	3% - 6%	210-420
Transmission Technologies		
Production-Intent Transmission Technologies		
Continuously Variable Transmission (CVT)	4% - 8%	140-350
Five Speed Automatic Transmission	2% - 3%	70-154
Emerging Transmission Technologies		
Automatic Shift/Manual Transmission	3% - 5%	70-280
Advanced Continuously Variable Transmission	0% - 2%	350-840
Automatic Transmission with Aggressive Shift Logic	1% - 3%	__ - 70
Six-Speed Automatic Transmission	1% - 2%	140-280
Vehicle Technologies		
Production-Intent Vehicle Technologies		
Aerodynamic drag reduction on vehicle designs	1% - 2%	__ - 140
Improved Rolling Resistance	1% - 1½%	14 – 56
Emerging Vehicle Technologies		
42 Volt Electrical System	1% - 2%	70 - 280
Integrated Starter/Generator (idle off-restart)	4% - 7%	210 - 350
Electric Power Steering	1.5% - 2.5%	105 - 150
Vehicle Weight Reduction (5%)	3% - 4%	$210 - $350

Source: National Research Council, 2002.

With the exception of fuel cells, the technologies summarized in Table B-1 are all currently under production, product planning, or continued development, or they are the subject of future product introduction in Europe or Japan. The feasibility of production is therefore well known, as are the estimated production costs. However, within the competitive cost constraints of the U.S. market, only certain technologies are currently considered practical or cost effective for introduction into different vehicle classes.[1]

The Enhanced Vehicle Fuel Efficiency Standards Option

A major objective of our analysis was to estimate the economic and related impacts of changes in CAFE standards, and below we summarize how our CAFE scenario was derived. While the standards are hypothetical and are not intended to be recommended or preferred fuel economy standards, we tried to ensure that the scenario, while ambitious, is feasible in terms of technology, economics, and timing. A key source in devising these scenarios was the NRC report,[2] which, in turn, was based on extensive research of current practices and published research within the automotive industry.

As discussed above, there exist numerous engine, transmission, and vehicle technologies for incrementally increasing vehicle fuel efficiency, and these technologies and related cost estimates were the starting point for developing the scenario utilized here. However, the implied relationships between increased fuel efficiency and incremental costs are not necessarily linear, and there are a large number of possible fuel economy increases and resulting cost increases that are possible.

A key issue that must be addressed in any discussion of increasing CAFE standards is the level of cost increases that may be justified by the resulting increased vehicle fuel efficiency. While there may be legitimate environmental, security, and other reasons for increasing CAFE standards, the tradeoff between improved fuel efficiency and increased vehicle cost is of critical importance. The NRC addressed this issue by estimating the point at which the incremental costs of new technology begin to exceed the marginal savings in fuel costs and derived an objective measure of how much fuel economy could be increased while still decreasing consumers' transportation costs. The NRC termed this the "cost-efficient level of fuel economy improvement," because it minimizes the sum of vehicle and fuel costs while holding other vehicle attributes constant. We relied on the NRC's analysis of the estimated incremental fuel efficiency benefits and the incremental costs of technologies -- illustrated in Table B-1 -- and constructed our scenario of increased CAFE standards.

[1]At present, three manufactures, Ford, Honda, and Toyota, sell hybrid gasoline-electric vehicles in the U.S. market.
[2]National Research Council, op. cit.

We believe that our scenario "pushes the envelope" on the fuel efficiency gains possible from current or impending technologies. It assumes that:

- The legislation is enacted in year t_0, the enhanced CAFE standards are phased in starting in year $t_0 + 3$, and attain full implementation in year $t_0 + 8$.
- The fuel efficiency gains possible from incremental technologies are available or likely to be available within the next decade as discussed in the NRC report and other studies are implemented.
- CAFE standards are increased 50 percent by year $t_0 + 8$.
- The new CAFE standards remain at those levels after year $t_0 + 8$.
- Average vehicle prices increase about $2,700 (12 percent) for the 50 percent increase in mpg by year $t_0 + 8$.

Our scenario is our basis for determining what the likely costs and impacts of attaining these goals might be. We believe that the scenario is feasible and credible because it relies on technologies that are either currently available or well into the development phase. It does not require development of "new" vehicles or exotic technologies. The timetable involved, a 50 percent increase in mpg and eight years from legislation to full implementation, is congruent with the original CAFE timetable that mandated a 53 percent increase (18 mpg to 27.5 mpg) in the years between 1975 and 1985.[1]

However, our hypothesized CAFE increases may also be more challenging than those enacted during the 1970s: The original CAFE enhancements were obtained, in part, by relatively easy weight reductions and by capturing other "low hanging fruit." Future CAFE enhancements will require successful R&D and technological innovation.

In addition, the scenario assumes equal percentage fuel economy increases for passenger cars and for light trucks, while the NRC study and related data indicate that it may be desirable and more efficient to require larger fuel economy improvements for light trucks than for passenger cars.[2] Thus, our CAFE scenario may not be the most desirable scenario that could be constructed. For instance, at present light trucks are exempt from the fuel efficiency standards applicable to passenger vehicles, and requiring both vehicle types to achieve similar fuel efficiency improvements (as simulated here) would be a major accomplishment in and of itself.[3]

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[1]The scenario is somewhat more ambitious than the CAFE standard increases that were being considered by Congress in 2002 -- the most recent year in which a major effort to significantly increase CAFE standards was undertaken. For example: Senate Commerce Committee Chairman Ernest Hollings (D-S.C.) proposed raising the CAFE standard for passenger cars and light trucks to 37 mpg by 2014; Senate Commerce Committee ranking Republican John McCain (R-Ariz.) proposed raising the CAFE standard to 36 mpg by 2016; the bipartisan proposal by Senator McCain and Senator John Kerry (D-Mass.) proposed raising the CAFE standard to 35 mpg by 2015.

[2]The CAFE standards do not apply to heavy duty trucks, which account for about 16 percent of U.S. petroleum consumption.

[3]It should also be noted that price elasticities for specific vehicles or vehicle types were not estimated. Aside from the practical difficulties of estimating future price elasticities, increasing fuel economy implies

Finally, while the scenarios are technically feasible, there is no free lunch. Increased CAFE standards, no matter what the potential energy, environmental, economic, and employment impacts, will require that fuel economy enhancement be given priority over other vehicle characteristics, will increase the purchase price of vehicles, will require manufacturers to produce vehicles that they would not in the absence of the enhanced standards, and will require consumers to purchase vehicles that would not exist except for the enhanced standards.[1]

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trading off other vehicle characteristics, such as horsepower and performance, for increased fuel efficiency. This would change the characteristics of vehicles, compared to what they otherwise would have been in the absence of enhanced CAFE standards. This would impact sales and price elasticities, especially among different classes of vehicles. While it is recognized that these effects would occur, a comprehensive analysis of them was outside the scope of the work conducted here.

[1]The potential impact of vehicle fuel efficiency standards on vehicle safety is especially contentious. The NRC report concluded that enhanced CAFE standards would increase risk, although several committee member dissented – see National Research Council, op. cit.

APPENDIX C
ADDITIONAL PERSPECTIVES

It is useful to note that:

- In 2005, U.S. liquid fuels consumption was about 21 MM bpd, of which about 13 MM bpd (62 percent) was imported and about 14 MM bpd (67 percent) was used in transportation
- In 2030 the EIA reference case forecasts that U.S. liquid fuels consumption will total about 28 MM bpd, of which about 17 MM bpd (61 percent) will be imported and 20 MM bpd (71 percent) will be used in transportation[1]
- As noted, the simultaneous initiation of all four of the mitigation options – VFE, CTL, oil shale, and EOR will, annually, in year t_0+20 produce or save about 14 MM bpd of liquid fuels

The 14 MM bpd of liquid fuels used in U.S. transportation in 2005 represents:

- Over 100 percent of U.S. 2005 liquid fuels imports of 13 MM bpd
- 50 percent of forecast total U.S. 2030 liquid fuels consumption and 82 percent of forecast U.S. 2030 liquid fuels imports
- 70 percent of forecast U.S. 2030 liquid fuels used in transportation

Cumulative costs over 20 years of $2.6 trillion for the crash program analyzed in this study can be viewed in the following context:

- U.S. GDP in 2005 was about $12.5 trillion (2004 dollars).
- EIA forecasts that in 2026 U.S. GDP will increase to about $23 trillion (2004 dollars).
- Cumulative GDP over the next 20 years is likely to total nearly $350 trillion, so the required $2.6 trillion in cumulative crash program costs over 20 years comprises less than one percent of likely cumulative GDP.

A useful measure of relative cost is real (2004 dollars) investment:

- In 2005, U.S. real investment totaled about $2 trillion.
- EIA forecasts that in 2026 U.S. real investment will increase to about $4.5 trillion (2004 dollars).[2]
- Cumulative real investment over the next 20 years is likely to total about $60 trillion (2004 dollars).

[1]U.S. Energy information Administration, Annual Energy Outlook, 2006, February 2006.
[2]Ibid.

On this basis, the calculated $2.6 trillion in cumulative costs over 20 years for the mitigation program considered in this report comprises only about four percent of likely cumulative real investment.

APPENDIX D
RECOMMENDATIONS FOR FURTHER RESEARCH

1. Assessment of Constraints

In this study four physical mitigation options for implementation in the U.S. were analyzed. Minimal supply side constraints on crash mitigation program implementation were assumed. However, if the U.S. decides to pursue aggressive mitigation options to reduce its imported oil dependence, it will require the shifting of huge, almost unprecedented, quantities of capital, technology, and labor, and there are major supply-side constraints that may impede such a strategy.

The U.S. may be hard-pressed to find the physical and human resources in adequate numbers to plan, develop, construct, and operate the plants and infrastructure required. For example, the equipment required will be in short supply, and the manpower required – engineers, scientists, chemists, skilled technicians and workers, etc. – may not be available in the required numbers. Equipment and technology will have to be purchased from foreign sources, and some of the labor may originate from foreign countries. This implies that the options may take longer and be more expensive to implement than estimated in this study. Given that oil peaking is a world problem, it is virtually certain that at the same time the U.S. is embarking on aggressive mitigation options, similar initiatives will also be undertaken elsewhere in the world, there by straining world capabilities and resources.

Analysis of the impacts of such constraints is needed. Factors to be assessed include the coal supply system and infrastructure, specialized capital resources and markets, available U.S. technology and industrial capacity, and adequacy of U.S. specialized professional, technical, and skilled workers.

2. Cost Escalations Associated with Crash Program Mitigation

The costs used in the calculations herein involved estimates for so-called nth plants – the plants that will be built in the third or fourth generation following the first ones. If ambitious programs like the ones described here were to be undertaken, early cost escalations will be quite large due to huge demands that will far outstrip existing supply. Such cost escalations could be of the order of factors of 2-10 in some instances. Analysis is needed to determine what these escalations might be in order to more accurately estimate total program costs and to better inform policy making.

3. Assessment of Other Mitigation Options

Other savings and substitute liquid fuel sources could be exploited in the U.S. For instance, U.S. biomass resources are significant and deserve careful analysis. Commercial ethanol and biodiesel liquid fuels production is already established. Cellulosic ethanol may be capable of producing large quantities of liquid fuels. Analysis of biomass options is especially important because they represent the only renewable energy technology that may be capable of efficiently producing large amounts of substitute liquid fuels for the transportation sector.

In addition, there are significant heavy oil resources in several western states and in Alaska that may contribute on a significant scale. Importantly, there are a number of fuel efficiency options whose implementation could have significant impact, particularly in the long-term. These and other options need to be carefully assessed and their likely costs estimated.

4. Institutional and Environmental Impediments to Mitigation Programs

Rapid implementation of the various mitigation options could have many important long-term advantages to the U.S. However, new industrial operations and facilities normally take years to plan, design, be sited, and constructed. Today, there are significant environmental, institutional, and political barriers that will inhibit the rapid implementation assumed in this study. Analysis is needed to identify and examine issues that will slow the progress of such projects and to provide options for acceleration for use by federal, state, and local governments and industry.

5. Stabilization of U.S. Oil Imports

It would be useful to assess how the mitigation options considered here might affect U.S. oil dependence and reliance on oil imports in greater detail over time. For example, several scenarios could be examined for the time period through 2030, including reducing the rate of growth of U.S. oil imports, reducing U.S. oil imports from the Middle East by some large fraction, maintaining a set level of oil imports, and/or gradually reducing the absolute level of U.S. oil imports.

APPENDIX E: PEAKING OF WORLD OIL PRODUCTION

A. Background

Oil was formed by geological processes millions of years ago and is typically found in underground reservoirs of dramatically different sizes, at varying depths, and with widely varying characteristics. The largest oil reservoirs are called “Super Giants,” many of which were discovered in the Middle East. Because of their size and other characteristics, Super Giant reservoirs are generally the easiest to find, the most economic to develop, and the longest lived. The last Super Giant oil reservoirs discovered worldwide were found in 1967 and 1968. Since then, smaller reservoirs of varying sizes have been discovered in what are called “oil prone” locations worldwide -- oil is not found everywhere.

Geologists understand that oil is a finite resource in the earth’s crust, and at some future date, world oil production will reach a maximum -- a peak -- after which production will decline. This logic follows from the well-established fact that the output of individual oil reservoirs rises after discovery, reaches a peak and declines thereafter. Oil reservoirs have lifetimes typically measured in decades, and peak production often occurs roughly a decade or so after discovery. It is important to recognize that <u>oil production peaking is not “running out</u>.” Peaking is a reservoir’s maximum oil production rate, which typically occurs after roughly half of the recoverable oil in a reservoir has been produced. In many ways, what is likely to happen on a world scale is similar to what happens to individual reservoirs, because world production is the sum total of production from many different reservoirs.

Because oil is usually found thousands of feet below the surface and because oil reservoirs normally do not have an obvious surface signature, oil is very difficult to find. Advancing technology has greatly improved the discovery process and reduced exploration failures. Nevertheless, oil exploration is still inexact and expensive.

Once oil has been discovered via an exploratory well, full-scale production requires many more wells across the reservoir to provide multiple paths that facilitate the flow of oil to the surface. This multitude of wells also helps to define the total recoverable oil in a reservoir – its so-called “reserves.”

B. Oil Reserves

The concept of reserves is generally not well understood. “Reserves” is an estimate of the amount of oil in a reservoir that can be extracted at an assumed cost. Thus, a higher oil price outlook often means that more oil can be produced, but geology places an upper limit on price-dependent reserves growth; in well managed oil fields, it is often 10-20 percent more than what is available at lower prices.

Reserves estimates are revised periodically as a reservoir is developed and new information provides a basis for refinement. Reserves estimation is a matter of gauging how much extractable oil resides in complex rock formations that exist typically one to three miles below the surface of the ground, using inherently limited information. Reserves estimation is a bit like a blindfolded person trying to judge what the whole elephant looks like from touching it in just a few places. It is not like counting cars in a parking lot, where all the cars are in full view.

Specialists who estimate reserves use an array of methodologies and a great deal of judgment. Thus, different estimators might calculate different reserves from the same data. Sometimes politics or self-interest influences reserves estimates, e.g., an oil reservoir owner may want a higher estimate in order to attract outside investment or to influence other producers.

Reserves and production should not be confused. Reserves estimates are but one factor in estimating future oil production from a given reservoir. Other factors include production history, understanding of local geology, available technology, oil prices, etc. An oil field can have large estimated reserves, but if the field is past its maximum production, the remaining reserves will be produced at a declining rate. This concept is important because satisfying increasing oil demand not only requires continuing to produce older oil reservoirs with their declining production, it also requires finding new ones, capable of producing sufficient quantities of oil to both compensate for shrinking production from older fields and to provide the increases demanded by the market.

C. Production Peaking

World oil demand is expected to grow nearly 50 percent by 2025.[1] To meet that demand, ever-larger volumes of oil will have to be produced. Since oil production from individual reservoirs grows to a peak and then declines, new reservoirs must be continually discovered and brought into production to compensate for the depletion of older reservoirs. If large quantities of new oil are not discovered and brought into production somewhere in the world, then world oil production will no longer satisfy demand. That point is called the peaking of world conventional oil production.

When world oil production peaks, there will still be large reserves remaining. Peaking means that the rate of world oil production cannot increase; it also means that production will thereafter decrease with time.

The peaking of world oil production has been a matter of speculation from the beginning of the modern oil era in the mid 1800s. In the early days, little was known about petroleum geology, so predictions of peaking were no more than guesses without basis. Over time, geological understanding improved dramatically and guessing gave way to more informed projections, although the knowledge base involves numerous uncertainties even today.

[1]U.S. Department of Energy, Energy Information Administration, *International Energy Outlook – 2006*, February 2004.

Past predictions typically fixed peaking in the succeeding 10-20 year period. Most such predictions were wrong, which does not negate that peaking will someday occur. Obviously, we cannot know if recent forecasts are wrong until predicted dates of peaking pass without incident.

With a history of failed forecasts, why revisit the issue now? The reasons are as follows:

1. Extensive drilling for oil and gas has provided a massive worldwide database; current geological knowledge is much more extensive than in years past, i.e., we have the knowledge to make much better estimates than previously.

2. Seismic and other exploration technologies have advanced dramatically in recent decades, greatly improving our ability to discover new oil reservoirs. Nevertheless, the oil reserves discovered per exploratory well began dropping worldwide over a decade ago. We are finding less and less oil in spite of vigorous efforts, suggesting that nature may not have much more to provide.

3. Many credible analysts have recently become much more pessimistic about the possibility of finding the huge new reserves needed to meet growing world demand.

4. Even the most optimistic forecasts suggest that world oil peaking will occur in less than 25 years.

5. The peaking of world oil production could create enormous economic disruption, as only glimpsed during the 1973 oil embargo and the 1979 Iranian oil cut-off.

Accordingly, there are compelling reasons for in-depth, unbiased reconsideration.

D. Types of Oil

Oil is classified as “Conventional” and “Unconventional.” Conventional oil is typically the highest quality, lightest oil, which flows from underground reservoirs with comparative ease. Unconventional oils are heavy, often tar-like. They are not readily recovered since production typically requires a great deal of capital investment and supplemental energy in various forms. For that reason, most current world oil production is conventional oil.[1]

[1]Ibid.

E. Oil Resources[1]

Consider the world resource of conventional oil. In the past, higher prices led to increased estimates of conventional oil reserves worldwide. However, this price-reserves relationship has its limits, because oil is found in discrete packages (reservoirs) as opposed to the varying concentrations characteristic of many minerals. Thus, at some price, world reserves of recoverable conventional oil will reach a maximum because of geological fundamentals. Beyond that point, insufficient additional conventional oil will be recoverable at any realistic price. This is a geological fact that is often misunderstood by people accustomed to dealing with hard minerals, whose geology is fundamentally different. This misunderstanding often clouds rational discussion of oil peaking.

Future world recoverable reserves are the sum of the oil remaining in existing reservoirs plus the reserves to be added by future oil discoveries. Future oil production will be the sum of production from older reservoirs in decline, newer reservoirs from which production is increasing, and yet-to-be discovered reservoirs.

Because oil prices have been relatively high for the past decade, oil companies have conducted extensive exploration over that period, but their results have been disappointing. If recent trends hold, there is little reason to expect that exploration success will dramatically improve in the future. This situation is evident in Figure E-1, which shows the difference between annual world oil reserves additions minus annual consumption.[2] The image is one of a world moving from a long period in which reserves additions were much greater than consumption, to an era in which annual additions are falling increasingly short of annual consumption. This is but one of a number of trends that suggest the world is fast approaching the inevitable peaking of conventional world oil production.

[1]Total oil in place is called the "resource." However, only a part of the resource can be produced, because of geological complexities and economic limitations. That which is realistically recoverable is called "reserves," which varies within limits depending on oil prices.
[2]Aleklett, K. & Campbell, C.J. *"The Peak and Decline of World Oil and Gas Production".* Uppsala University, Sweden. ASPO web site. 2003.

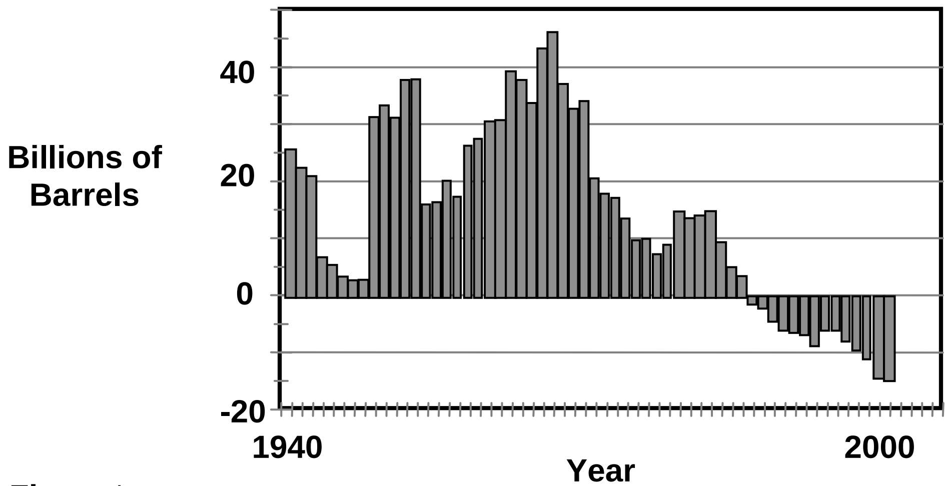

Figure E-1. Net Difference Between Annual World Oil Reserves Additions and Annual Consumption

F. Impact of Higher Prices and New Technology

Conventional oil has been the mainstay of modern civilization for more than a century, because it is most easily brought to the surface from deep underground reservoirs, and it is the most easily refined into finished fuels. The U.S. was endowed with huge reserves of petroleum, which underpinned U.S. economic growth in the early and mid twentieth century. However, U.S. oil resources, like those in the world, are finite, and growing U.S. demand resulted in the peaking of U.S. oil production in the Lower 48 states in the early 1970s. With relatively minor exceptions, U.S. Lower 48 oil production has been in continuing decline ever since. Because U.S. demand for petroleum products continued to increase, the U.S. became an oil importer. Today, the U.S. depends on foreign sources for almost 60 percent of its needs, and future U.S. imports are projected to rise even further by 2030.[1]

Over the past 50 years, exploration for and production of petroleum has been an increasingly more technological enterprise, benefiting from more sophisticated engineering capabilities, advanced geological understanding, improved instrumentation, greatly expanded computing power, more durable materials, etc. Today's technology allows oil reservoirs to be more readily discovered and better understood sooner than heretofore. Accordingly, reservoirs can be produced more rapidly, which provides significant economic advantages to the operators but also hastens peaking and depletion.

[1]U.S. Department of Energy, Energy Information Administration, *International Energy Outlook – 2006,* op.cit.

Some economists expect higher oil prices and improved technologies to continue to provide ever-increasing oil production for the foreseeable future. Most geologists disagree because they do not believe that there are many huge new oil reservoirs left to be found. Accordingly, geologists and other observers believe that supply will eventually fall short of growing world demand – and result in the peaking of world conventional oil production.

To gain some insight into the effects of higher oil prices and improved technology on oil production, let us briefly examine related impacts in the U.S. Lower 48 states. This region is a useful surrogate for the world, because it was one of the world's richest, most geologically varied, and most productive up until 1970, when production peaked and started into decline. While the U.S. is the best available surrogate, it should be remembered that the decline rate in US production was in part impacted by the availability of large volumes of relatively low cost oil from the Middle East.

Figure E-2 shows EIA data for Lower 48 oil production,[1] to which trend lines have been added that will aid our scenarios analysis later in the report. The trend lines show a relatively symmetric, triangular pattern. For reference, four notable petroleum market events are noted in the figure: the 1973 OPEC oil embargo, the 1979 Iranian oil crisis, the 1986 oil price collapse, and the 1991 Iraq war.

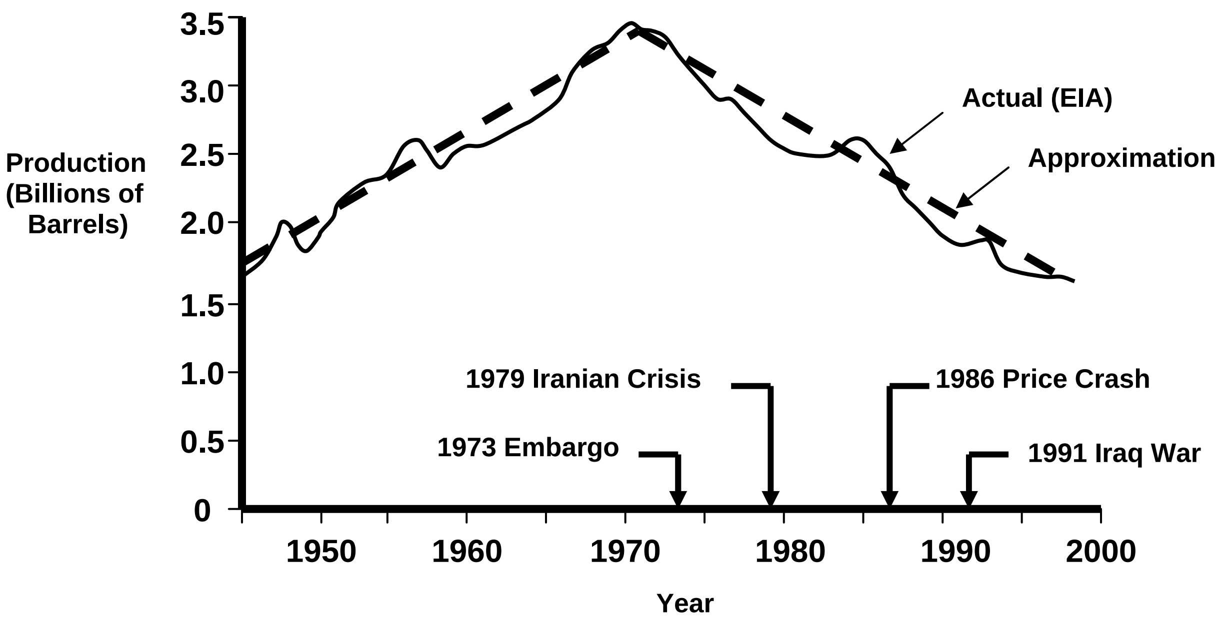

Figure E-2. U.S. Lower 48 Oil Production, 1945-2000

Figure E-3 shows Lower 48 historical oil production with oil prices and technology trends added. In constant dollars, oil prices increased by roughly a factor of three in 1973-74 and another factor of two in 1979-80. The modest production up-ticks in the

[1]U.S. Department of Energy, Energy Information Administration, *Long Term World Oil Supply*, April 18, 2000.

mid 1980s and early 1990s are likely responses to the 1973 and 1979 oil price spikes, both of which spurred a major increase in U.S exploration and production investments. The delays in production response are inherent to the implementation of large-scale oil field investments. The fact that the production up-ticks were moderate was due to the absence of attractive exploration and production opportunities, because of geological realities.

Beyond oil price increases, the 1980s and 1990s were a golden age of oil field technology development, including practical 3-D seismic, economic horizontal drilling, and dramatically improved geological understanding. Nevertheless, as Figure E-3 shows, Lower 48 production still trended downward, showing no pronounced response to either price or technology. In light of this experience, there is good reason to expect that an analogous situation will exist worldwide after world oil production peaks: Higher prices and improved technology are unlikely to yield dramatically higher conventional oil production.[1]

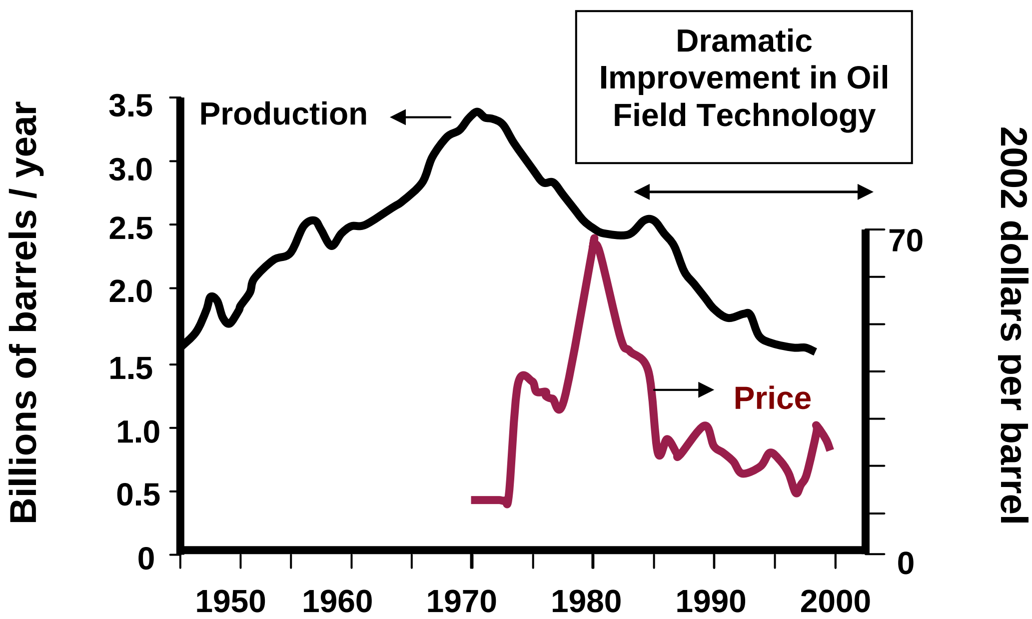

Figure E-3. Lower 48 Oil Production and Oil Prices

G. Projections of the Peaking of World oil Production

Projections of future world oil production will be the sum total of 1) output from all of the world's then existing producing oil reservoirs, which will be in various stages of

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[1]The US Lower 48 experience occurred over a long period characterized at different times by production controls (Texas Railroad Commission), price and allocation controls (1970s), free market prices (since 1981), wild price swings, etc., as well as higher prices and advancing technology. Nevertheless, production peaked and moved into a relatively constant rate of decline.

development, and 2) all the yet-to-be discovered reservoirs in their various states of development. This is an extremely complex summation problem, because of the variability and possible biases in publicly available data. In practice, estimators use various approximations to predict future world oil production. The remarkable complexity of the problem can easily lead to incorrect conclusions, either positive or negative.

Various individuals and groups have used available information and geological estimates to develop projections for when world oil production might peak. A sampling of recent projections is shown in Table E-1.

Table E-1. Projections of the Peaking of World Oil Production

Projected Date	Source of Projection	Background & Reference
2006-2007	Bakhitari, A.M.S.	Iranian Oil Executive[1]
2007-2009	Simmons, M.R.	Investment banker [2]
After 2007	Skrebowski, C.	Petroleum journal Editor [3]
Before 2009	Deffeyes, K.S.	Oil company geologist (ret.) [4]
Before 2010	Goodstein, D.	Vice Provost, Cal Tech [5]
Around 2010	Campbell, C.J.	Oil company geologist (ret.) [6]
After 2010	World Energy Council	World Non-Government Org.[7]
2010-2020	Laherrere, J.	Oil company geologist (ret.) [8]
2016	EIA nominal case	DOE analysis/ information[9]
After 2020	CERA	Energy consultants [10]
2025 or later	Shell	Major oil company [11]
No visible peak	Lynch, M.C.	Energy economist[12]

[1]Bakhtiari, A.M.S. "World Oil Production Capacity Model Suggests Output Peak by 2006-07." *OGJ*. April 26, 2004.
[2]Simmons, M.R. ASPO Workshop. May 26, 2003.
[3]Skrebowski, C. "Oil Field Mega Projects - 2004." *Petroleum Review*. January 2004.
[4]Deffeyes, K.S. *Hubbert's Peak-The Impending World Oil Shortage*. Princeton University Press. 2003.
[5]Goodstein, D. *Out of Gas – The End of the Age of Oil*. W.W. Norton. 2004
[6]Campbell, C.J. "Industry Urged to Watch for Regular Oil Production Peaks, Depletion Signals." *OGJ*. July 14, 2003.
[7]*Drivers of the Energy Scene*. World Energy Council. 2003.
[8]Laherrere, J. Seminar Center of Energy Conversion. Zurich. May 7, 2003
[9]DOE EIA. "Long Term World Oil Supply." April 18, 2000. See Appendix I for discussion.
[10]Jackson, P. et al. "Triple Witching Hour for Oil Arrives Early in 2004 – But, As Yet, No Real Witches." *CERA Alert*. April 7, 2004.
[11]Davis, G. "Meeting Future Energy Needs." *The Bridge.* National Academies Press. Summer 2003.
[12]Lynch, M.C. "Petroleum Resources Pessimism Debunked in Hubbert Model and Hubbert Modelers' Assessment." *Oil and Gas Journal,* July 14, 2003.