United States Government Accountability Office

GAO

Report to Congressional Requesters

February 2007

CRUDE OIL

Uncertainty about Future Oil Supply Makes It Important to Develop a Strategy for Addressing a Peak and Decline in Oil Production

GAO-07-283

GAO Accountability·Integrity·Reliability

Highlights

Highlights of GAO-07-283, a report to congressional requesters

Why GAO Did This Study

The U.S. economy depends heavily on oil, particularly in the transportation sector. World oil production has been running at near capacity to meet demand, pushing prices upward. Concerns about meeting increasing demand with finite resources have renewed interest in an old question: How long can the oil supply expand before reaching a maximum level of production—a peak—from which it can only decline?

GAO (1) examined when oil production could peak, (2) assessed the potential for transportation technologies to mitigate the consequences of a peak in oil production, and (3) examined federal agency efforts that could reduce uncertainty about the timing of a peak or mitigate the consequences. To address these objectives, GAO reviewed studies, convened an expert panel, and consulted agency officials.

What GAO Recommends

To better prepare for a peak in oil production, GAO recommends that the Secretary of Energy work with other agencies to establish a strategy to coordinate and prioritize federal agency efforts to reduce uncertainty about the likely timing of a peak and to advise Congress on how best to mitigate consequences. In commenting on a draft of the report, the Departments of Energy and the Interior generally agreed with the report and recommendations.

www.gao.gov/cgi-bin/getrpt?GAO-07-283.

To view the full product, including the scope and methodology, click on the link above. For more information, contact Jim Wells at (202) 512-3841 or wellsj@gao.gov.

February 2007

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Uncertainty about Future Oil Supply Makes It Important to Develop a Strategy for Addressing a Peak and Decline in Oil Production

What GAO Found

Most studies estimate that oil production will peak sometime between now and 2040. This range of estimates is wide because the timing of the peak depends on multiple, uncertain factors that will help determine how quickly the oil remaining in the ground is used, including the amount of oil still in the ground; how much of that oil can ultimately be produced given technological, cost, and environmental challenges as well as potentially unfavorable political and investment conditions in some countries where oil is located; and future global demand for oil. Demand for oil will, in turn, be influenced by global economic growth and may be affected by government policies on the environment and climate change and consumer choices about conservation.

In the United States, alternative fuels and transportation technologies face challenges that could impede their ability to mitigate the consequences of a peak and decline in oil production, unless sufficient time and effort are brought to bear. For example, although corn ethanol production is technically feasible, it is more expensive to produce than gasoline and will require costly investments in infrastructure, such as pipelines and storage tanks, before it can become widely available as a primary fuel. Key alternative technologies currently supply the equivalent of only about 1 percent of U.S. consumption of petroleum products, and the Department of Energy (DOE) projects that even by 2015, they could displace only the equivalent of 4 percent of projected U.S. annual consumption. In such circumstances, an imminent peak and sharp decline in oil production could cause a worldwide recession. If the peak is delayed, however, these technologies have a greater potential to mitigate the consequences. DOE projects that the technologies could displace up to 34 percent of U.S. consumption in the 2025 through 2030 time frame, if the challenges are met. The level of effort dedicated to overcoming challenges will depend in part on sustained high oil prices to encourage sufficient investment in and demand for alternatives.

Federal agency efforts that could reduce uncertainty about the timing of peak oil production or mitigate its consequences are spread across multiple agencies and are generally not focused explicitly on peak oil. Federally sponsored studies have expressed concern over the potential for a peak, and agency officials have identified actions that could be taken to address this issue. For example, DOE and United States Geological Survey officials said uncertainty about the peak's timing could be reduced through better information about worldwide demand and supply, and agency officials said they could step up efforts to promote alternative fuels and transportation technologies. However, there is no coordinated federal strategy for reducing uncertainty about the peak's timing or mitigating its consequences.

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Abbreviations

CO_2	carbon dioxide
DOE	Department of Energy
DOT	Department of Transportation
EIA	Energy Information Administration
EOR	enhanced oil recovery
GDP	gross domestic product
GTL	gas to liquids
IEA	International Energy Agency
OECD	Organization for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
USDA	United States Department of Agriculture
USGS	United States Geological Survey

GAO
Accountability * Integrity * Reliability

United States Government Accountability Office
Washington, DC 20548

February 28, 2007

The Honorable Bart Gordon
Chairman
Committee on Science and Technology
House of Representatives

The Honorable Roscoe G. Bartlett
The Honorable Judy Biggert
The Honorable Wayne T. Gilchrest
The Honorable Vernon J. Ehlers
The Honorable Lynn C. Woolsey
House of Representatives

U.S. consumers paid $38 billion more for gasoline in the first 6 months of 2006 than they paid in the same period of 2005, and $57 billion more than they paid in the same period of 2004, in large part because of rising oil prices, which reached a 24-year high in 2006 when adjusted for inflation. Oil is a global commodity, and its price is determined mainly by the balance between world demand and supply. Since 1983, world consumption of petroleum products has grown fairly steadily. The Department of Energy's (DOE) Energy Information Administration (EIA) states in a 2006 report that world consumption of petroleum had reached 84 million barrels per day in 2005.[1] EIA also projects that world oil consumption will continue to grow and will reach 118 million barrels per day in 2030.[2] About 43 percent of this growth in oil consumption will come from the non-Organization for Economic Co-operation and Development Asian countries, including China and India, but the United States will remain the world's largest oil consumer. In 2005, the United States accounted for just under 25 percent of world oil consumption. World oil

[1]This number comes from EIA's *Monthly Energy Review (*December 2006), table 11.2. EIA labels this table as petroleum consumption, but DOE pointed out in its comments that the consumption data include some ethanol, which is not a petroleum product. EIA staff told us that the ethanol in the 2005 figure amounts to 265,000 barrels per day, amounting to just under one-third of 1 percent of world consumption.

[2]This projection comes from EIA's *International Energy Outlook 2006* and reflects assumptions used in EIA's reference case scenario. To assess uncertainties in the reference case projections, EIA also runs low and high oil price scenarios, in which the projected world oil consumption in 2030 is 102 million and 128 million barrels per day, respectively.

production has been running at near capacity in recent years to meet rising consumption, putting upward pressure on oil prices. The potential for disruptions in key oil-producing regions of the world, such as the Middle East, and the yearly threat of hurricanes in the Gulf of Mexico have also exerted upward pressure on oil prices. These conditions have renewed interest in a long-standing question: Will oil supply continue to expand to meet growing demand, or will we soon reach a maximum possible level of production—a peak—beyond which oil supply can only decline?

Historically, U.S. oil production peaked around 1970 at close to 10 million barrels per day and has been generally declining ever since, to about 5 million barrels per day in 2005. While recent discoveries raise the prospect of some increases in U.S. oil production, significant reductions in world oil production could still have important consequences for the nation's welfare. The United States imported about 66 percent of its oil and petroleum products in 2005, and the U.S. economy—particularly the transportation sector—depends heavily on oil. Overall, transportation accounts for approximately 65 percent of U.S. oil consumption. New technologies have been introduced that displace some oil consumption within the sector, but oil consumption for transportation has continued to increase in recent years. According to a 2005 report prepared for DOE, without timely preparation, a reduction in world oil production could cause transportation fuel shortages that would translate into significant economic hardship.[3]

The U.S. government addresses or examines world oil supply in several ways. For example, DOE is responsible for promoting the nation's energy security through reliable and affordable energy, including oil. DOE supports development of technologies for producing and using oil and for making alternative fuels, such as ethanol or hydrogen. The department also publishes statistics on energy production and consumption through EIA. In addition, the United States Geological Survey (USGS), within the Department of the Interior (Interior), assesses the amount of oil throughout the world. The United States also is a member of the International Energy Agency (IEA), an organization of 26 member countries whose objectives include coping with disruptions in the oil

[3]Robert L. Hirsch, Roger Bezdek, and Robert Wendling, *Peaking of World Oil Production: Impacts, Mitigation, and Risk Management* (February 2005).

supply and providing information on the international oil market, among other things.[4]

In this context, we (1) examined when oil production could peak, (2) assessed the potential for transportation technologies to mitigate the consequences of a peak and decline in oil production, and (3) examined federal agency efforts that could reduce uncertainty about the timing of peak oil production or mitigate the consequences.

In conducting our work, we identified and reviewed key studies on when oil production will peak. We reviewed estimates of the amount of oil throughout the world and the amount of oil held by national oil companies, and we analyzed forecasts of political and investment risks in oil-producing regions. To assess the potential for transportation technologies in the United States to mitigate the consequences of a peak and decline in oil production, we examined options to develop alternative fuels and technologies to reduce energy consumption in the transportation sector. In particular, we focused on technologies that would affect automobiles and light trucks. We consulted with experts to devise a list of key technologies in these areas and then reviewed DOE programs and activities related to developing these technologies. We did not attempt to comprehensively list all technologies or to conduct a governmentwide review of all programs, and we limited our scope to what federal government officials know about the status of these technologies in the United States. We did not conduct a global assessment of transportation technologies. We reviewed numerous studies on the relationship between oil and the global economy and, in particular, on the experiences of past oil price shocks. To identify federal government activities that could address peak oil production issues, we spoke with officials at DOE and USGS, and gathered information on federal programs and policies that could affect uncertainty about the timing of peak oil production and the development of alternative transportation technologies. To gain further insights into the federal role and other issues surrounding peak oil production, we convened an expert panel in conjunction with the National Academy of Sciences. These experts commented on the potential economic consequences of a transition away from conventional oil, factors that could affect the severity of the consequences, and what the federal role should be, among other things. A more detailed description of the scope and methodology of our review is presented in appendix I. We

[4]The European Commission also participates in the work of IEA.

performed our work between July 2005 and December 2006, in accordance with generally accepted government auditing standards.

Results in Brief

Most studies estimate that oil production will peak sometime between now and 2040, although many of these projections cover a wide range of time, including two studies for which the range extends into the next century. The timing of the peak depends on multiple, uncertain factors that will influence how quickly the remaining oil is used, including the amount of oil still in the ground, how much of the remaining oil can be ultimately produced, and future oil demand. The amount of oil remaining in the ground is highly uncertain, in part because the Organization of Petroleum Exporting Countries (OPEC) controls most of the estimated world oil reserves, but its estimates of reserves are not verified by independent auditors. In addition, many parts of the world have not yet been fully explored for oil. There is also great uncertainty about the amount of oil that will ultimately be produced, given the technological, cost, and environmental challenges. For example, some of the oil remaining in the ground can be accessed only by using complex and costly technologies that present greater environmental challenges than the technologies used for most of the oil produced to date. Other important sources of uncertainty about future oil production are potentially unfavorable political and investment conditions in countries where oil is located. For example, more than 60 percent of world oil reserves, on the basis of *Oil and Gas Journal* estimates, are in countries where relatively unstable political conditions could constrain oil exploration and production. Finally, future world demand for oil also is uncertain because it depends on economic growth and government policies throughout the world. For example, continued rapid economic growth in China and India could significantly increase world demand for oil, while environmental concerns, including oil's contribution to global warming, may spur conservation or adoption of alternative fuels that would reduce future demand for oil.

In the United States, alternative transportation technologies face challenges that could impede their ability to mitigate the consequences of a peak and decline in oil production, unless sufficient time and effort are brought to bear. For example:

- Ethanol from corn is more costly to produce than gasoline, in part because of the high cost of the corn feedstock. Even if ethanol were to become more cost-competitive with gasoline, it could not become widely available without costly investments in infrastructure, including pipelines, storage tanks, and filling stations.

- Advanced vehicle technologies that could increase mileage or use different fuels are generally more costly than conventional technologies and have not been widely adopted. For example, hybrid electric vehicles can cost from $2,000 to $3,500 more to purchase than comparable conventional vehicles and currently constitute about 1 percent of new vehicle registrations in the United States.

- Hydrogen fuel cell vehicles are significantly more costly than conventional vehicles to produce. Specifically, the hydrogen fuel cell stack needed to power a vehicle currently costs about $35,000 to produce, in comparison with a conventional gas engine, which costs $2,000 to $3,000.

Given these challenges, development and widespread adoption of alternative transportation technologies will take time and effort. Key alternative technologies currently supply the equivalent of only about 1 percent of U.S. consumption of petroleum products, and DOE projects that even under optimistic scenarios, by 2015 these technologies could displace only the equivalent of 4 percent of projected U.S. annual consumption. Under these circumstances, an imminent peak and sharp decline in oil production could have severe consequences, including a worldwide recession. If the peak comes later, however, these technologies have a greater potential to mitigate the consequences. DOE projects that these technologies could displace up to the equivalent of 34 percent of projected U.S. annual consumption of petroleum products in the 2025 through 2030 time frame, assuming the challenges the technologies face are overcome. The level of effort dedicated to overcoming challenges to alternative technologies will depend in part on the price of oil; without sustained high oil prices, efforts to develop and adopt alternatives may fall by the wayside.

Federal agency efforts that could reduce uncertainty about the timing of peak oil production or mitigate its consequences are spread across multiple agencies and generally are not focused explicitly on peak oil. For example, efforts that could be used to reduce uncertainty about the timing of a peak include USGS activities to estimate oil resources and DOE efforts to monitor current supply and demand conditions in global oil markets and to make future projections. Similarly, DOE, the Department of Transportation (DOT), and the U.S. Department of Agriculture (USDA) all have programs and activities that oversee or promote alternative transportation technologies that could mitigate the consequences of a peak. However, officials of key agencies we spoke with acknowledge that their efforts—with the exception of some studies—are not specifically designed to address peak oil. Federally sponsored studies we reviewed have expressed a growing concern over the potential for a peak and officials from key agencies have identified some options for addressing this issue. For example, DOE and USGS officials told us that developing better information about worldwide demand and supply and improving global estimates for nonconventional oil resources and oil in “frontier” regions that have yet to be fully explored could help prepare for a peak in oil production by reducing uncertainty about its timing. Agency officials also said that, in the event of an imminent peak, they could step up efforts to mitigate the consequences by, for example, further encouraging development and adoption of alternative fuels and advanced vehicle technologies. However, according to DOE, there is no formal strategy for coordinating and prioritizing federal efforts dealing with peak oil issues, either within DOE or between DOE and other key agencies.

While the consequences of a peak would be felt globally, the United States, as the largest consumer of oil and one of the nations most heavily dependent on oil for transportation, may be particularly vulnerable. Therefore, to better prepare the United States for a peak and decline in oil production, we are recommending that the Secretary of Energy take the lead, in coordination with other relevant federal agencies, to establish a peak oil strategy. Such a strategy should include efforts to reduce uncertainty about the timing of a peak in oil production and provide timely advice to Congress about cost-effective measures to mitigate the potential consequences of a peak. In commenting on a draft of the report, the Departments of Energy and the Interior generally agreed with the report and recommendations.

Background

Oil—the product of the burial and transformation of biomass over the last 200 million years—has historically had no equal as an energy source for its intrinsic qualities of extractability, transportability, versatility, and cost. But the total amount of oil underground is finite, and, therefore, production will one day reach a peak and then begin to decline. Such a peak may be involuntary if supply is unable to keep up with growing demand. Alternatively, a production peak could be brought about by voluntary reductions in oil consumption before physical limits to continued supply growth kick in. Not surprisingly, concerns have arisen in recent years about the relationship between (1) the growing consumption of oil and the availability of oil reserves and (2) the impact of potentially dwindling supplies and rising prices on the world’s economy and social welfare. Following a peak in world oil production, the rate of production would eventually decrease and, necessarily, so would the rate of consumption of oil.

Oil can be found and produced from a variety of sources. To date, world oil production has come almost exclusively from what are considered to be “conventional sources” of oil. While there is no universally agreed-upon definition of what is meant by conventional sources, IEA states that conventional sources can be produced using today’s mainstream technologies, compared with “nonconventional sources” that require more complex or more expensive technologies to extract, such as oil sands and oil shale. Distinguishing between conventional and nonconventional oil sources is important because the additional cost and technological challenges surrounding production of nonconventional sources make these resources more uncertain. However, this distinction is further complicated because what is considered to be a mainstream technology can change over time. For example, offshore oil deposits were considered to be a nonconventional source 50 years ago; however, today they are considered conventional. For the purpose of this report, and consistent with IEA’s classification, we define nonconventional sources as including oil sands, heavy oil deposits, and oil shale.[5] Some oil is being produced from these nonconventional sources today. For example, in 2005 Canada produced about 1.6 million barrels per day of oil from oil sands, and Venezuelan production of extra-heavy oil for 2005 was projected to be about 600,000 barrels per day. Currently, however, production from these sources is very small compared with total world oil production.

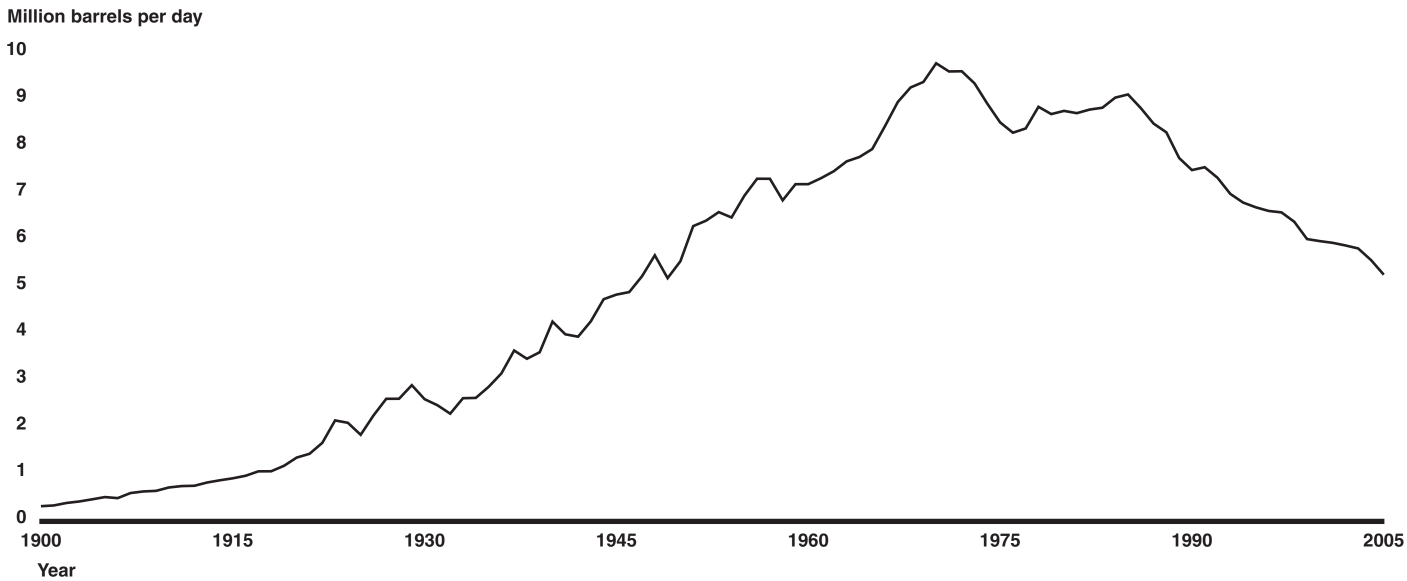
Oil Production Has Peaked in the United States and Most Other Countries Outside the Middle East

According to IEA, most countries outside the Middle East have reached their peak in conventional oil production, or will do so in the near future. The United States is a case in point. Even though the United States is currently the third-largest, oil-producing nation,[6] U.S. oil production peaked around 1970 and has been on a declining trend ever since. (See fig. 1.)

[5]The distinction as to what portion of heavy oil is conventional is debated by experts. For example, contrary to the IEA definition, USGS considers the heavy oil produced in California as conventional oil.

[6]Saudi Arabia and Russia, respectively, lead in world oil production.

Figure 1: U.S. Oil Production, 1900-2005



Source: GAO analysis of Energy Information Administration data.

Looking toward the future, EIA projects that U.S. deepwater oil production will slightly boost total U.S. production in the near term. However, this increase will end about 2016, and then U.S. production will continue to decline. Given these projections, it is clear that future increases in U.S. demand for oil will need to be fulfilled through increases in production in the rest of the world. Increasing production in other countries has to date been able to more than make up for declining U.S. production and has resulted in increasing world production. (See fig. 2.)

Figure 2: World Crude Oil and Other Liquids Production, 1965-2005

Source: GAO analysis of British Petroleum data.

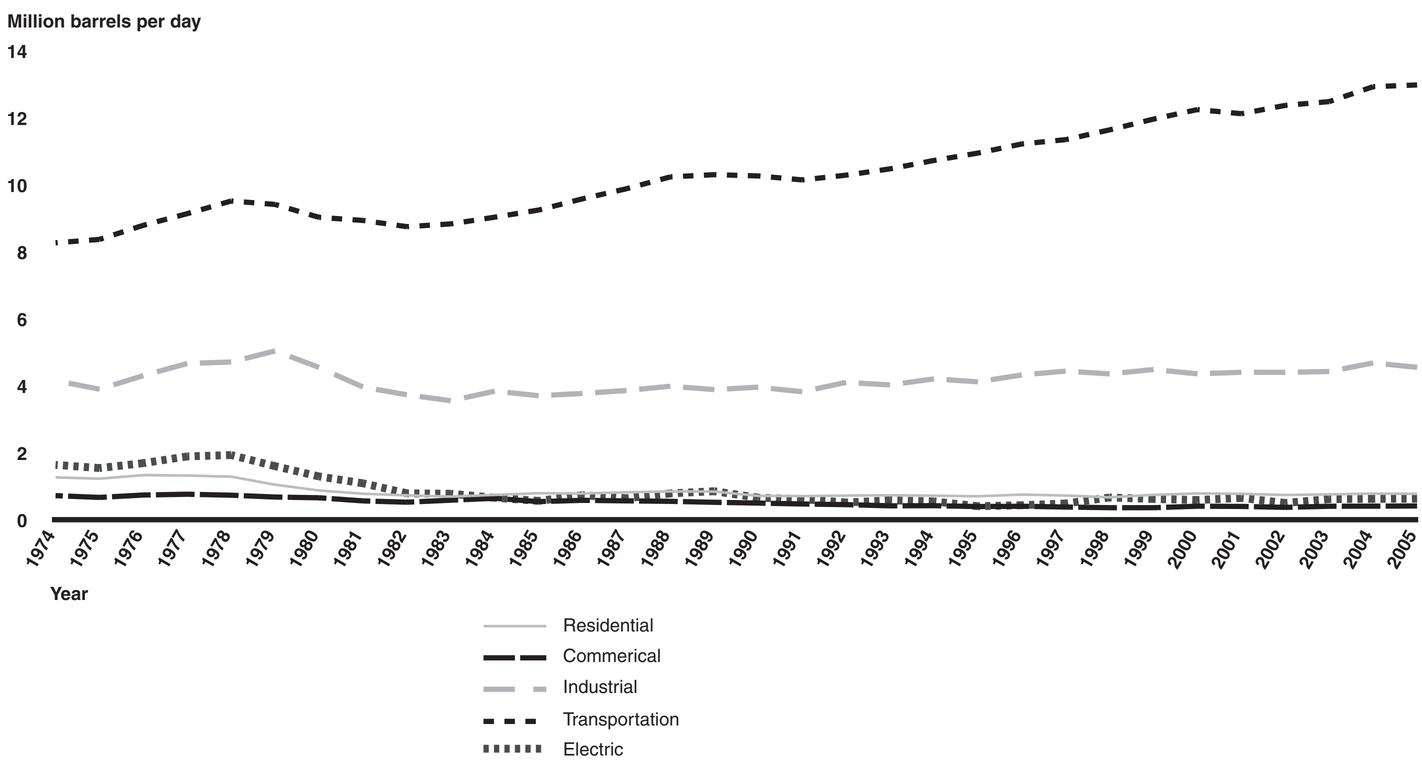
Note: These data include crude oil, shale oil, oil sands, and natural gas liquids—the liquid content of natural gas. They exclude liquid fuels from other sources, such as coal derivatives.

Oil Is Critical in Satisfying the U.S. and World Demand for Energy

Oil accounts for approximately one-third of all the energy used in the world. Following the record oil prices associated with the Iranian Revolution in 1979-80 and with the start of the Iran-Iraq war in 1980, there was a drop in total world oil consumption, from about 63 million barrels per day in 1980 to 59 million barrels per day in 1983. Since then, however, world consumption of petroleum products has increased, totaling about 84 million barrels per day in 2005. In the United States, consumption of petroleum products increased an average of 1.65 percent annually from 1983 to 2004, and averaged 20.6 million barrels per day in 2005, representing about one-quarter of all world consumption. EIA projects that U.S. consumption will continue to increase and will reach 27.6 million barrels per day in 2030.

As figure 3 shows, the transportation sector is by far the largest U.S. consumer of petroleum, accounting for two-thirds of all U.S. consumption and relying almost entirely on petroleum to operate. Within the transportation sector, light vehicles are the largest consumers of petroleum energy,[7] accounting for approximately 60 percent of the transportation sector's consumption of petroleum-based energy in the United States. Figure 3 also shows that while consumption of petroleum products in other sectors has remained relatively constant or increased slightly since the early 1980s, petroleum consumption in the transportation sector has grown at a significant rate.

Figure 3: Annual U.S. Oil Consumption, by Sector, 1974-2005



Source: GAO analysis of Energy Information Administration data.

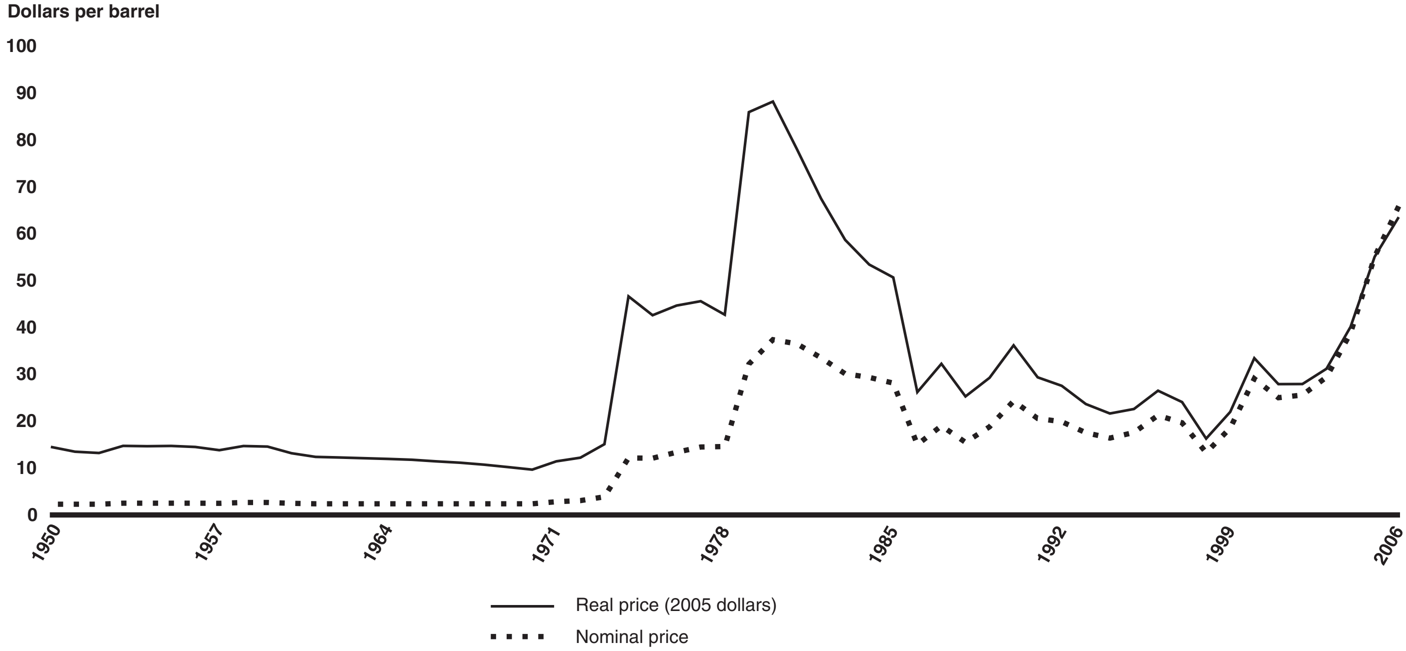
Relationship of Supply and Demand of Oil to Oil Price

The price of oil is determined in the world market and depends mainly on the balance between world demand and supply. Recent world production of oil has been running at near capacity to meet rising demand, which has put upward pressure on oil prices. Figure 4 shows that world oil prices in nominal terms—unadjusted for inflation—are higher than at any time

[7] According to the *Transportation Energy Data Book*, light vehicles include cars; light trucks (two-axle, four-tire trucks); and motorcycles.

since 1950, although when adjusted for inflation, the high prices of 2006 are still lower than were reached in the 1979-80 price run-up following the Iranian Revolution and the beginning of the Iran-Iraq war.

Figure 4: Real and Nominal Oil Prices, 1950-2006



Source: GAO analysis of British Petroleum, Energy Information Administration, and Bureau of Labor Statistics data.

Note: Crude oil price data are annual averages of Arabian Light prices for 1945 through 1983 and Brent oil prices for 1984 through 2005. The 2006 price is an average of daily Brent oil prices from January 3 to December 20, 2006.

All else being equal, oil consumption is inversely correlated with oil price, with higher oil prices inducing consumers to reduce their oil consumption.[8] Specifically, increases in crude oil prices are reflected in the prices of products made from crude oil, including gasoline, diesel, home heating oil, and petrochemicals. The extent to which consumers are

[8]Oil consumption also depends on other factors; therefore, it is sometimes difficult to isolate the changes in consumption caused by changes in oil prices. For example, gasoline consumption generally increases as incomes rise and people choose to drive more. In addition, higher incomes mean that oil plays a smaller role in a consumer's budget, and, therefore, higher-income consumers may be less sensitive to changes in oil prices than lower-income consumers.

willing and able to reduce their consumption of oil in response to price increases depends on the cost of switching to activities and lifestyles that use less oil. Because there are more options available in the longer term, consumers respond more to changes in oil prices in the longer term than in the shorter term. For example, in the short term, consumers can reduce oil consumption by driving less or more slowly, but in the longer term, consumers can still take those actions, but can also buy more fuel-efficient automobiles or even move closer to where they work and thereby further reduce their oil consumption.

Supply and demand, in turn, affect the type of oil that is produced. Conventional oil that is less expensive to extract using lower-cost drilling techniques will be produced when oil prices are lower. Conversely, oil that is expensive to produce because of the higher cost technologies involved may not be economical to produce at low oil prices. Producers are unlikely to turn to these more expensive oil sources unless oil prices are sustained at a high enough level to make such an enterprise profitable. Given the importance of oil in the world's energy portfolio, as cheaper oil reserves are exhausted in the future, nations will need to make the transition to more and more expensive and difficult-to-access sources of oil to meet energy demands. Recently, for example, a large discovery of oil in the Gulf of Mexico made headlines; however, this potential wealth of oil is located at a depth of over 5 miles below sea level, a fact that adds significantly to the costs of extracting that oil.

Timing of Peak Oil Production Depends on Uncertain Factors

Most studies estimate that oil production will peak sometime between now and 2040, although many of these projections cover a wide range of time, including two studies for which the range extends into the next century.[9] Key uncertainties in trying to determine the timing of peak oil are the (1) amount of oil throughout the world; (2) technological, cost, and environmental challenges to produce that oil; (3) political and investment risk factors that may affect oil exploration and production; and (4) future world demand for oil. The uncertainties related to exploration and

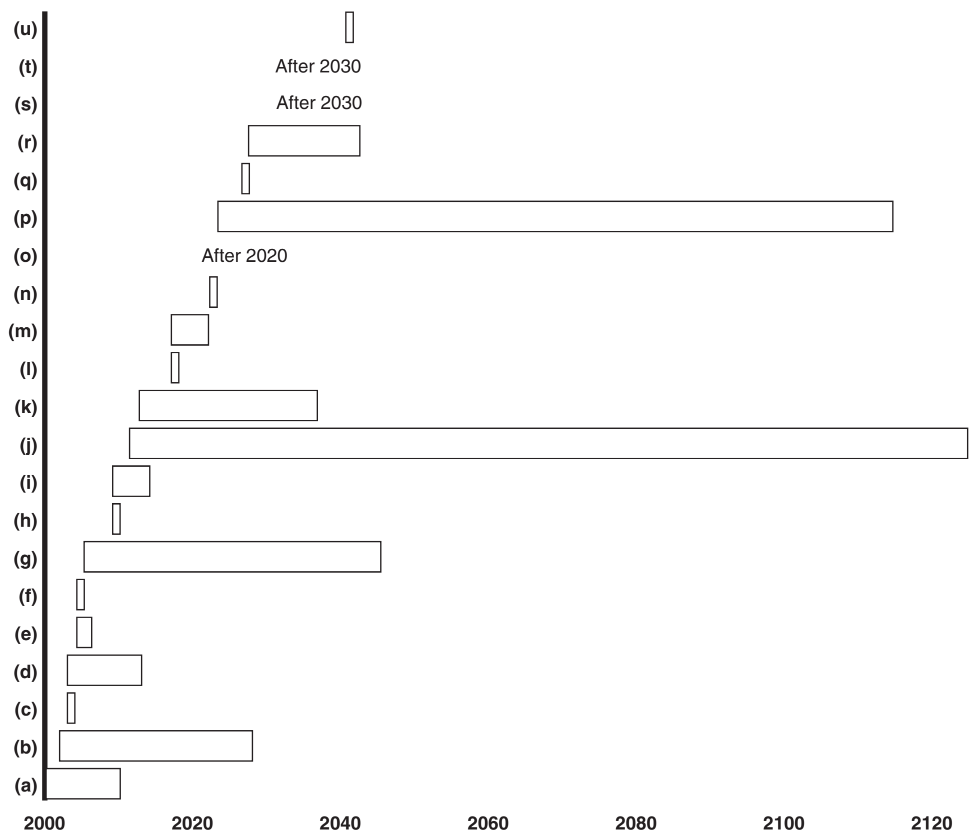
[9] One key difference between the studies is in how much oil they assume is still in the ground. Some studies consider a peak in conventional oil, while other studies consider a peak in total oil, including conventional and nonconventional oils. Because of these differences in the peak concept used in the various studies, we have not attempted to define a peak as either a peak in conventional oil or conventional plus nonconventional oils. Instead, we have focused on identifying key factors that cause uncertainty in the timing of the peak. These factors would cause such uncertainty regardless of whether the peak concept focused on conventional or total oil.

production also make it difficult to estimate the rate of decline after the peak.

Studies Predict Widely Different Dates for Peak Oil

Most studies estimate that oil production will peak sometime between now and 2040, although many of these projections cover a wide range of time, including two studies for which the range extends into the next century. Figure 5 shows the estimates of studies we examined.

Figure 5: Key Estimates of the Timing of Peak Oil



Source: GAO study.

Note: These studies are listed in appendix II of this report. Estimates of 90 percent confidence intervals using two different reserves data sources are provided for study g. One additional study that is not represented in this figure, referenced as study v, states that the timing of the peak is "unknowable."

Amount of Oil in the Ground Is Uncertain

Studies that predict the timing of a peak use different estimates of how much oil remains in the ground, and these differences explain some of the wide ranges of these predictions. Estimates of how much oil remains in the ground are highly uncertain because much of these data are self-reported and unverified by independent auditors; many parts of the world have yet to be fully explored for oil; and there is no comprehensive assessment of oil reserves from nonconventional sources. This uncertainty surrounding estimates of oil resources in the ground comprises the uncertainty surrounding estimates of proven reserves[10] as well as uncertainty surrounding expected increases in these reserves and estimated future oil discoveries.

Oil and Gas Journal and *World Oil*, two primary sources of proven reserves estimates, compile data on proven reserves from national and private company sources. Some of this information is publicly available from oil companies that are subject to public reporting requirements—for example, information provided by companies that are publicly traded on U.S. stock exchanges that are subject to the filing requirements of U.S. federal securities laws. Information filed pursuant to these laws is subject to liability standards, and, therefore, there is a strong incentive for these companies to make sure their disclosures are complete and accurate. On the other hand, companies that are not subject to these federal securities laws, including companies wholly owned by various OPEC countries where the majority of reserves are located, are not subject to these filing requirements and their related liability standards. Some experts believe OPEC estimates of proven reserves to be inflated. For example, OPEC estimates increased sharply in the 1980s, corresponding to a change in OPEC's quota rules that linked a member country's production quota in part to its remaining proven reserves. In addition, many OPEC countries' reported reserves remained relatively unchanged during the 1990s, even as they continued high levels of oil production. For example, IEA reports that reserves estimates in Kuwait were unchanged from 1991 to 2002, even though the country produced more than 8 billion barrels of oil over that period and did not make any important new oil discoveries. At a 2005

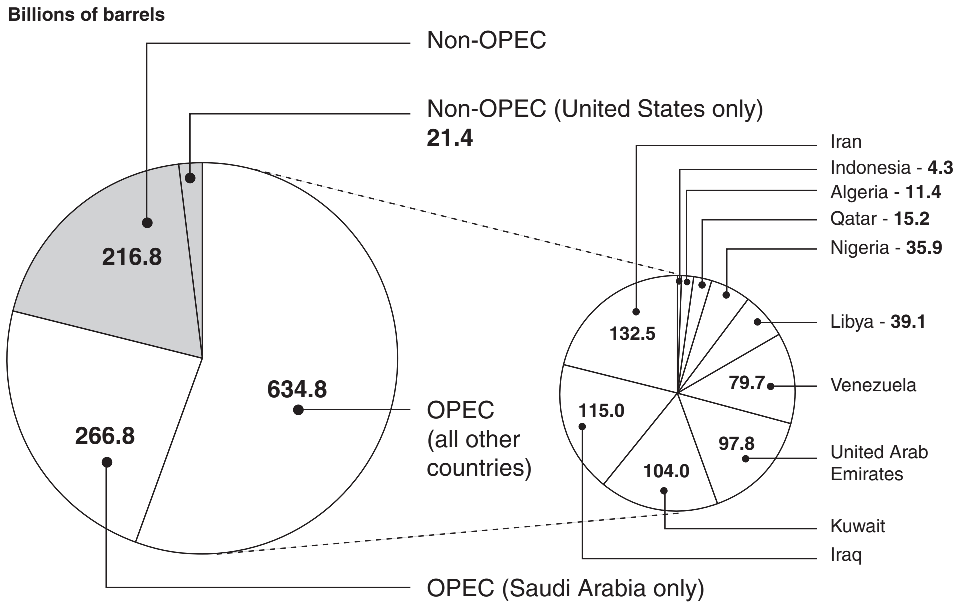
[10]Proven reserves are classified as oil in the ground that is likely to be economically producible at expected oil prices and given expected technologies. Conventional reserves are often classified according to the degree of certainty that they exist and can be extracted profitably. Even this classification is fraught with uncertainty because there are no harmonized rules about the assumptions to be used when determining this profitability.

National Academy of Sciences workshop on peak oil, OPEC defended its reserves estimates as accurate. The potential unreliability of OPEC's self-reported data is particularly problematic with respect to predicting the timing of a peak because OPEC holds most of the world's current estimated proven oil reserves. On the basis of *Oil and Gas Journal* estimates as of January 2006, we found that of the approximately 1.1 trillion barrels of proven oil reserves worldwide,[11] about 80 percent are located in the OPEC countries,[12] compared with about 2 percent in the United States. Figure 6 shows this estimate in more detail.

[11]As previously discussed in this report, there is no universally agreed-upon definition of conventional oil. The *Oil and Gas Journal* includes Canadian oil sands in its estimates. IEA classifies oil sands as nonconventional, and, therefore, since we are using the IEA classification throughout this report, we have removed the *Oil and Gas Journal* estimate of 174 billion barrels of oil from the Canadian oil sands data. USGS experts emphasized the importance of these oil sands in future oil production and stated that in their view, these resources are now considered to be conventional.

[12]OPEC's members are Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela. Beginning with January 2007 data, new OPEC member Angola would also be included in OPEC reserves estimates.

Figure 6: World Oil Reserves, OPEC and non-OPEC, 2006



Source: GAO analysis of *Oil and Gas Journal* data.

USGS, another primary source of reported estimates, provides oil resources estimates, which are different from proved reserves estimates. Oil resources estimates are significantly higher because they estimate the world's total oil resource base, rather than just what is now proven to be economically producible. USGS estimates of the resource base include past production and current reserves as well as the potential for future increases in current conventional oil reserves—often referred to as reserves growth—and the amount of estimated conventional oil that has the potential to be added to these reserves.[13] Estimates of reserves growth and those resources that have the potential to be added to oil reserves are important in determining when oil production may peak. However,

[13]USGS defines conventional oil accumulation based primarily on geology. The time horizon for these data is 30 years. This definition does not incorporate economic or political factors, such as deepwater, remoteness, harsh climate, regulatory status, or engineering techniques. Not included in this USGS definition are oil sands and oil shale. Interior's Minerals Management Service oversees oil production on federal lands offshore. Officials from the Minerals Management Service stated in comments on a draft of this report that, with regard to some offshore areas, resource estimates are based on data that are 20 to 25 years old. They also pointed out that resource estimates can change dramatically with improvements to technology and information.

estimating these potential future reserves is complicated by the fact that many regions of the world have not been fully explored and, as a result, there is limited information. For example, in its 2000 assessment, USGS provides a mean estimate of 732 billion barrels that have the potential to be added as newly discovered conventional oil, with as much as 25 percent from the Arctic—including Greenland, Northern Canada, and the Russian portion of the Barents Sea. However, relatively little exploration has been done in this region, and there are large portions of the world where the potential for oil production exists, but where exploration has not been done. According to USGS, there is less uncertainty in regions where wells have been drilled, but even in the United States, one of the areas that has seen the greatest exploration, some areas have not been fully explored, as illustrated by the recent discovery of a potentially large oil field in the Gulf of Mexico.

Limited information on oil-producing regions worldwide also leads USGS to base its estimate of reserves growth on how reserves estimates have grown in the United States. However, some experts criticize this methodology; they believe such an estimate may be too high because the U.S. experience overestimates increases in future worldwide reserves. In contrast, EIA believes the USGS estimate may be too low. In 2005, USGS released a study showing that its prediction of reserves growth has been in line with the world's experience from 1996 to 2003.[14] Given such controversy, uncertainty remains about this key element of estimating the amount of oil in the ground. In 2000, USGS' most recent full assessment of the world's key oil regions, the agency provided a range of estimates of remaining world conventional oil resources. The mean of this range was at about 2.3 trillion barrels comprising about 890 billion barrels in current reserves and 1.4 trillion barrels that have the potential to be added to oil reserves in the future.[15]

Further contributing to the uncertainty of the timing of a peak is the lack of a comprehensive assessment of oil from nonconventional sources. For example, the three key sources of oil estimates—*Oil and Gas Journal*,

[14]T.R. Klett, Donald L. Gautier, and Thomas S. Ahlbrandt, "An Evaluation of the U.S. Geological Survey World Petroleum Assessment 2000," *American Association of Petroleum Geologists Bulletin*. Vol. 89, no.8 (August 2005).

[15]Thomas S. Ahlbrandt, Ronald R. Charpentier, T.R. Klett, James W. Schmoker, Christopher J. Schenk, and Gregory F. Ulmishek, *Global Resource Estimates from Total Petroleum Systems* (The American Association of Petroleum Geologists: Tulsa, Oklahoma, 2005).

World Oil, and USGS—do not generally include oil from nonconventional sources. This is an important issue because oil from nonconventional sources is thought to exist in large quantities. For example, IEA believes that oil from nonconventional sources—composed primarily of Canadian oil sands, extra-heavy oil deposits in Venezuela, and oil shale in the United States—could account for as much as 7 trillion barrels of oil, which could greatly delay the onset of a peak in production. However, IEA also points out that the amount of this nonconventional oil that will eventually be produced is highly uncertain, which is a result of the challenges facing this production. Despite this uncertainty, USGS experts noted that Canadian oil sands and Venezuelan extra-heavy oil production are under way now and also suggested that proven reserves from these sources will be growing considerably in the immediate future.

Uncertainty Remains about How Much Oil Can Be Produced from Proven Reserves, Hard-to-Reach Locations, and Nonconventional Sources

It is also difficult to project the timing of a peak in oil production because technological, cost, and environmental challenges make it unclear how much oil can ultimately be recovered from (1) proven reserves, (2) hard-to-reach locations, and (3) nonconventional sources.

To increase the recovery rate from oil reserves, companies turn to enhanced oil recovery (EOR) technologies, which DOE reports has the potential to increase recovery rates from 30 to 50 percent in many locations. These technologies include injecting steam or heated water; gases, such as carbon dioxide; or chemicals into the reservoir to stimulate oil flow and allow for increased recovery. Opportunities for EOR have been most aggressively pursued in the United States, EOR technologies currently contribute approximately 12 percent to U.S. production, and carbon dioxide EOR alone is projected to have the potential to provide at least 2 million barrels per day by 2020. However, technological advances, such as better seismic and fluid-monitoring techniques for reservoirs during an EOR injection, may be required to make these techniques more cost-effective. Furthermore, EOR technologies are much costlier than the conventional production methods used for the vast majority of oil produced. Costs are higher because of the capital cost of equipment and operating costs, including the production, transportation, and injection of agents into existing fields and the additional energy costs of performing these tasks. Finally, EOR technologies have the potential to create environmental concerns associated with the additional energy required to conduct an EOR injection and the greenhouse gas emissions associated with producing that energy, although EIA has stated that these environmental costs may be less than those imposed by producing oil in previously undeveloped areas. Even if sustained high oil prices make EOR technologies cost-effective for an oil company, these challenges and costs may deter their widespread use.

The timing of peak oil is also difficult to estimate because new sources of oil could be increasingly more remote and costly to exploit, including offshore production of oil in deepwater and ultra-deepwater. Worldwide, industry analysts report that deepwater (depths of 1,000 to 5,000 feet) and ultra-deepwater (5,000 to 10,000 feet) drilling efforts are concentrated offshore in Africa, Latin America, and North America, and capital expenditures for these efforts are expected to grow through at least 2011. In the United States, deepwater and ultra-deepwater drilling, primarily in the Gulf of Mexico, could reach 2.2 million barrels per day in 2016, according to EIA estimates. However, accessing and producing oil from these locations present several challenges. At deepwater depths, penetrating the earth and efficiently operating drilling equipment is difficult because of the extreme pressure and temperature. In addition, these conditions can compromise the endurance and reliability of operating equipment. Operating costs for deepwater rigs are 3.0 to 4.5 times more than operating costs for typical shallow water rigs. Capital costs, including platforms and underwater pipeline infrastructures, are also greater. Finally, deepwater and ultra-deepwater drilling efforts generally face similar environmental concerns as shallow water drilling efforts, although some deepwater operations may pose greater environmental concerns to sensitive deepwater ecosystems.

It is unclear how much oil can be recovered from nonconventional sources. Recovery from these sources could delay a peak in oil production or slow the rate of decline in production after a peak. Expert sources disagree concerning the significance of the role these nonconventional sources will play in the future. DOE officials we spoke with emphasized the belief that nonconventional oil will play a significant role in the very near future as conventional oil production is unable to meet the increasing demand for oil. However, IEA estimates of oil production have conventional oil continuing to comprise almost all of production through 2030. Currently, production of oil from key nonconventional sources of oil—oil sands, heavy and extra-heavy oil deposits, and oil shale—is more costly and presents environmental challenges.

Oil Sands

Oil sands are deposits of bitumen, a thick, sticky form of crude oil, that is so heavy and viscous it will not flow unless heated. While most conventional crude oil flows naturally or is pumped from the ground, oil sands must be mined or recovered "in-situ," before being converted into an upgraded crude oil that can be used by refineries to produce gasoline and diesel fuels. Alberta, Canada, contains at least 85 percent of the world's proven oil sands reserves. In 2005, worldwide production of oil sands, largely from Alberta, contributed approximately 1.6 million barrels of oil per day, and production is projected to grow to as much as 3.5 million barrels per day by 2030. Oil sand deposits are also located domestically in Alabama, Alaska, California, Texas, and Utah. Production from oil sands, however, presents significant environmental challenges. The production process uses large amounts of natural gas, which generates greenhouse gases when burned. In addition, large-scale production of oil sands requires significant quantities of water, typically produce large quantities of contaminated wastewater, and alter the natural landscape. These challenges may ultimately limit production from this resource, even if sustained high oil prices make production profitable.

Heavy and Extra-Heavy Oils

Heavy and extra-heavy oils are dense, viscous oils that generally require advanced production technologies, such as EOR, and substantial processing to be converted into petroleum products. Heavy and extra-heavy oils differ in their viscosities and other physical properties, but advanced recovery techniques like EOR are required for both types of oil. Known extra-heavy oil deposits are primarily in Venezuela—almost 90 percent of the world's proven extra-heavy oil reserves. Venezuelan production of extra-heavy oil was projected to be 600,000 barrels of oil per day in 2005 and is projected to be sustained at this rate through 2040. Heavy oil can be found in Alaska, California, and Wyoming and may exist in other countries besides the United States and Venezuela. Like production from oil sands, however, heavy oil production in the United States presents environmental challenges in its consumption of other energy sources, which contributes to greenhouse gases, and potential groundwater contamination from the injectants needed to thin the oil enough so that oil will flow through pipes.

Oil Shale

Oil shale is sedimentary rock containing solid bituminous materials that release petroleum-like liquids when the rock is heated. The world's largest known oil shale deposit covers portions of Colorado, Utah, and Wyoming, but other countries, such as Australia and Morocco, also contain oil shale resources. Oil shale production is under consideration in the United States, but considerable doubts remain concerning its ultimate technical and commercial feasibility. Production from oil shale is energy-intensive, requiring other energy sources to heat the shale to about 900 to 1,000 degrees Fahrenheit to extract the oil. Furthermore, oil shale production is projected to contaminate local surface water with salts and toxics that leach from spent shale. These factors may limit the amount of oil from shale that can be produced, even if oil prices are sustained at high enough levels to offset the additional production costs.

More detailed information on these technologies is provided in appendix III.

Political and Investment Risk Factors Create Uncertainty about the Future Rate of Oil Exploration and Production

Political and investment risk factors also could affect future oil exploration and production and, ultimately, the timing of peak oil production. These factors include changing political conditions and investment climates in many countries that have large proven oil reserves. Experts we spoke with told us that they considered these factors important in affecting future oil exploration and production.

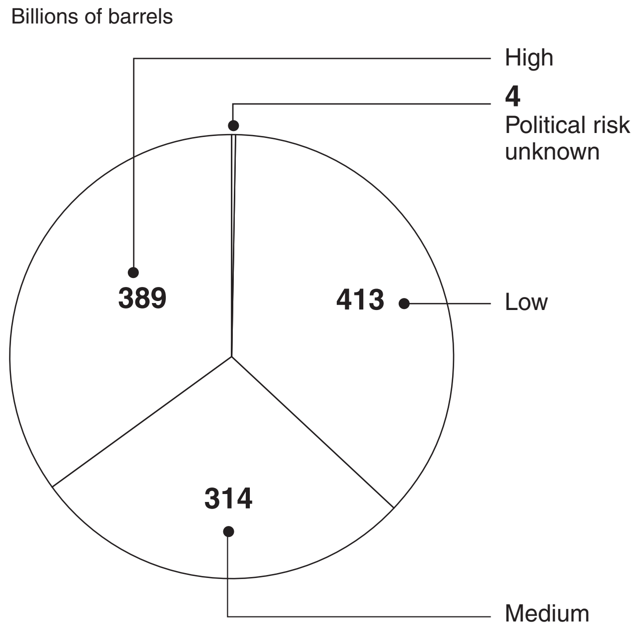
Political Conditions Create Uncertainties about Oil Exploration and Production

In many countries with proven reserves, oil production could be shut down by wars, strikes, and other political events, thus reducing the flow of oil to the world market. If these events occurred repeatedly, or in many different locations, they could constrain exploration and production, resulting in a peak despite the existence of proven oil reserves. For example, according to a news account, crude oil output in Iraq dropped from 3.0 million barrels per day before the 1990 gulf war to about 2.0 million barrels per day in 2006, and a labor strike in the Venezuelan oil sector led to a drop in exports to the United States of 1.2 million barrels. Although these were isolated and temporary oil supply disruptions, if enough similar events occurred with sufficient frequency, the overall impact could constrain production capacity, thus making it impossible for supply to expand along with demand for oil. Using a measure of political risk that assesses the likelihood that events such as civil wars, coups, and labor strikes will occur in a magnitude sufficient to reduce a country's gross domestic product (GDP) growth rate over the next 5 years,[16] we found that four countries—Iran, Iraq, Nigeria, and Venezuela—that possess proven oil reserves greater than 10 billion barrels (high reserves) also face high levels of political risk. These four countries contain almost

[16]The political risk measure comes from Global Insight's Global Risk Service. Global Insight is a worldwide consulting firm headquartered in Massachusetts. The Global Risk Service political risk score is a summary of probabilities that different political events, such as civil war, will reduce GDP growth rates. The subjective probabilities are assessed by country analysts at Global Insight, on the basis of a wide range of information, and are reviewed by a team to ensure consistency across countries. The measures are revised quarterly; the measure we used comes from the second quarter of 2006.

one-third of worldwide oil reserves. Countries with medium or high levels of political risk contained 63 percent of proven worldwide oil reserves, on the basis of *Oil and Gas Journal* estimates of oil reserves. (See fig. 7.)[17]

Figure 7: Worldwide Proven Oil Reserves, by Political Risk



Source: GAO analysis of *Oil and Gas Journal* and Global Insight data.

Note: *Oil and Gas Journal* reserves estimates are based on surveys filled out by the countries. See appendix I of this report for limitations of these data and their effect on our use of these data.

Even in the United States, political considerations may affect the rate of exploration and production. For example, restrictions imposed to protect environmental assets mean that some oil may not be produced. Interior's Minerals Management Service estimates that approximately 76 billion barrels of oil lie in undiscovered fields offshore in the U.S. outer continental shelf. However, Congress has enacted moratoriums on drilling and exploration in this area to protect coastlines from unintended oil

[17]Because we examined a forecast of risk factors, it would have been ideal to have a forecast of what oil reserves are likely to be in each country for the next 5 years, including reserve growth and potential future discoveries. However, such reserve predictions are not publicly available, and, therefore, we used published country-level data on proven reserves from the *Oil and Gas Journal*. Consistent with our previous presentation of proven reserves, the information we present here does not include Canadian oil sands data.

spills. In addition, policies on federal land use need to take into account multiple uses of the land, including environmental protection.[18] Environmental restrictions may affect a peak in oil production by barring oil exploration and production in environmentally sensitive areas.

Investment Climate Creates Uncertainty about Oil Exploration and Production

Foreign investment in the oil sector could be necessary to bring oil to the world market,[19] according to studies we reviewed and experts we consulted, but many countries have restricted foreign investment. Lack of investment could hasten a peak in oil production because the proper infrastructure might not be available to find and produce oil when needed, and because technical expertise may be lacking. The important role foreign investment plays in oil production is illustrated in Kazakhstan, where the National Commission on Energy Policy found that opening the energy sector to foreign investment in the early 1990s led to a doubling in oil production between 1998 and 2002.[20] In addition, we found that direct foreign investment in Venezuela was strongly correlated with oil production in that country, and that when foreign investment declined between 2001 and 2004, oil production also declined.[21] Industry officials told us that lack of technical expertise could lead to less sophisticated drilling techniques that actually reduce the ability to recover oil in more complex reservoirs. For example, according to industry officials, some Russian wells have difficulties with high water cut—that is, a high ratio of water to oil—making oil difficult to get out of the ground at current prices. This water cut problem stems from not using technically advanced methods when the wells were initially drilled. We have previously reported that the Venezuelan national oil company, PDVSA, lost technical expertise when it fired thousands of employees following a strike in 2002 and 2003. In contrast, other national oil companies, such as Saudi Aramco, are widely perceived to possess considerable technical expertise.

[18]GAO, *Oil and Gas Development: Increased Permitting Activity Has Lessened BLM's Ability to Meet Its Environmental Protection Responsibilities*, GAO-05-418 (Washington, D.C.: June 17, 2005).

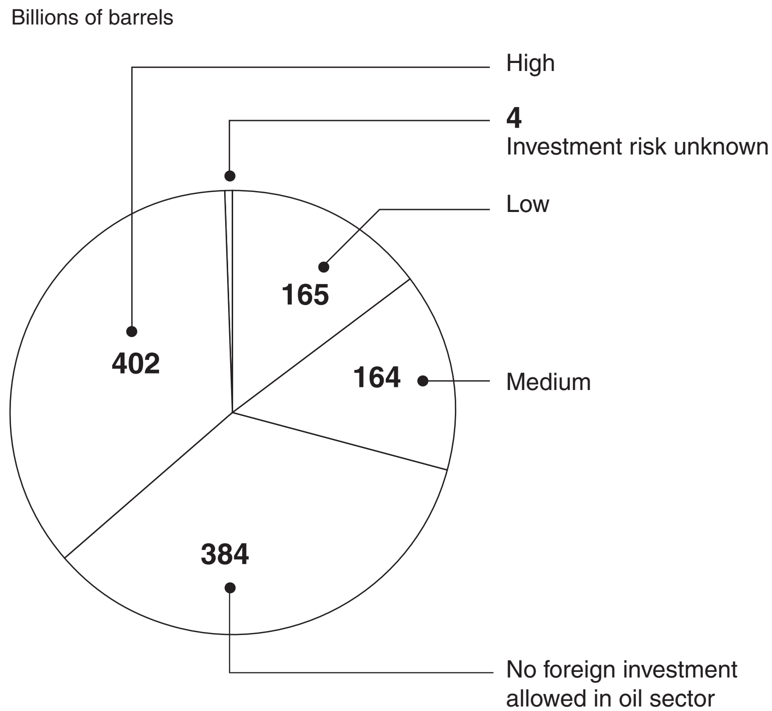
[19]According to IEA, infrastructure investment in exploration and production would need to total about $2.25 trillion from 2004 through 2030. This investment will be needed to expand supply capacity and to replace existing and future supply facilities that will be closed during the projection period.

[20]National Commission on Energy Policy, *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges* (December 2004), available at www.energycommission.org.

[21]GAO, *Energy Security: Issues Related to Potential Reductions in Venezuelan Oil Production*, GAO-06-668 (Washington, D.C.: June 27, 2006).

According to our analysis, 85 percent of the world's proven oil reserves are in countries with medium-to-high investment risk or where foreign investment is prohibited, on the basis of *Oil and Gas Journal* estimates of oil reserves. (See fig. 8.) For example, over one-third of the world's proven oil reserves lie in only five countries—China, Iran, Iraq, Nigeria, and Venezuela—all of which have a high likelihood of seeing a worsening investment climate. Three countries with large oil reserves—Saudi Arabia, Kuwait, and Mexico—prohibit foreign investment in the oil sector, and most major oil-producing countries have some type of restrictions on foreign investment. Furthermore, some countries that previously allowed foreign investment, such as Russia and Venezuela, appear to be reasserting state control over the oil sector, according to DOE.

Figure 8: Worldwide Proven Oil Reserves, by Investment Risk

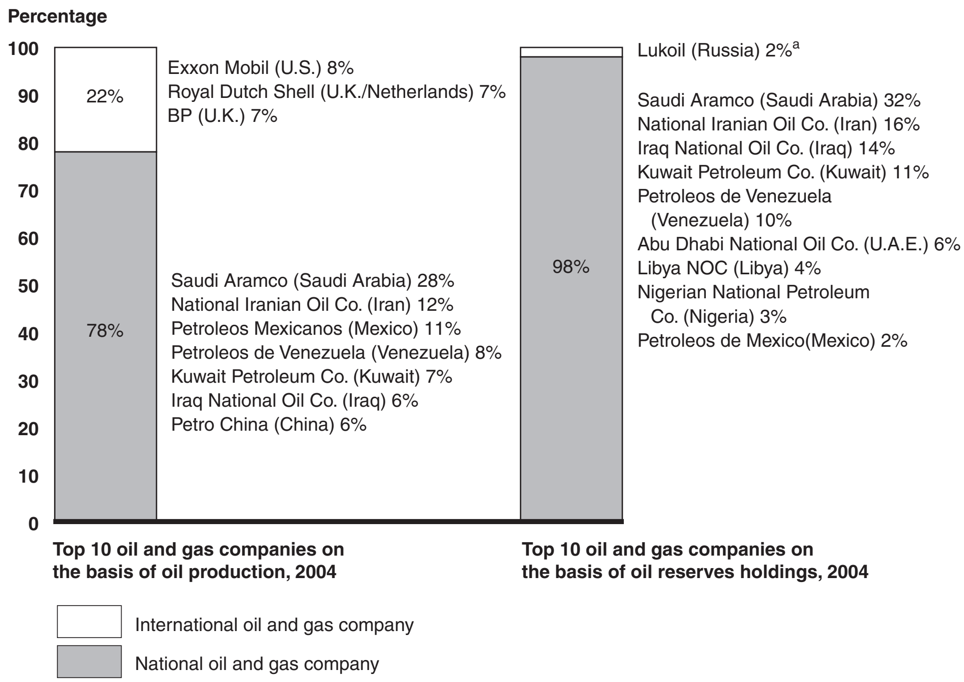


Source: GAO analysis of *Oil and Gas Journal* and Global Insight data.

Note: *Oil and Gas Journal* reserves estimates are based on surveys filled out by the countries. See appendix I of this report for limitations of these data and their effect on our use of these data.

Foreign investment in the oil sector also may be limited because national oil companies control the supply. Figure 9 indicates that 7 of the top 10 companies are national or state-sponsored oil and gas companies, ranked on the basis of oil production. The 3 international oil companies that are among the top 10 are BP, Exxon Mobil, and Royal Dutch Shell.

Figure 9: Top 10 Companies on the Basis of Oil Production and Reserves Holdings, 2004



Source: GAO analysis of data from *Petroleum Intelligence Weekly* (Dec. 12, 2005).

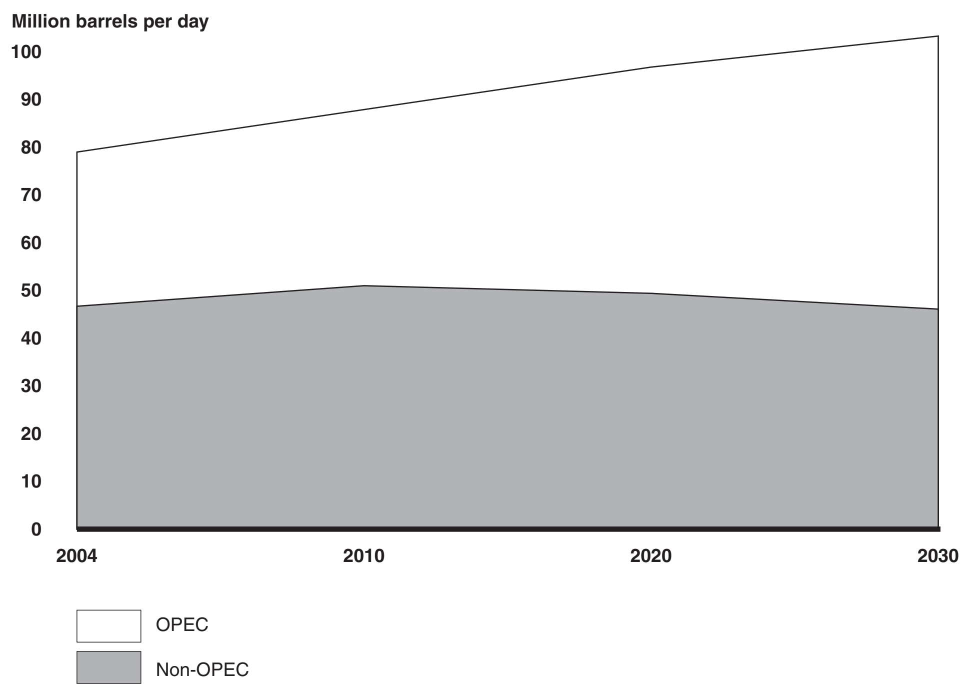
Note: The *Petroleum Intelligence Weekly* data relies on company reports, where possible, as well as other information sources provided by companies. See appendix I of this report for limitations of these data and their effect on our use of these data.

[a]Lukoil is the only company in the top 10 based on reserves that is not 100 percent state-sponsored.

National oil companies may have additional motivations for producing oil, other than meeting consumer demand. For instance, some countries use some profits from national companies to support domestic socioeconomic development, rather than focusing on continued development of oil exploration and production for worldwide consumption. Given the amount of oil controlled by national oil companies, these types of actions have the potential to result in oil production that is not optimized to respond to increases in the demand for oil.

In addition, the top 8 oil companies ranked by proven oil reserves are national companies in OPEC-member countries, and OPEC decisions could affect future oil exploration and production. For example, in some cases, OPEC countries might decide to limit current production to increase prices or to preserve oil and its revenue for future generations. Figure 10 shows IEA's projections for total world oil production through 2030 and highlights the larger role that OPEC production will play after IEA's projected peak in non-OPEC oil production around 2010.

Figure 10: World Oil Production, by OPEC and Non-OPEC Countries, 2004 Projected to 2030



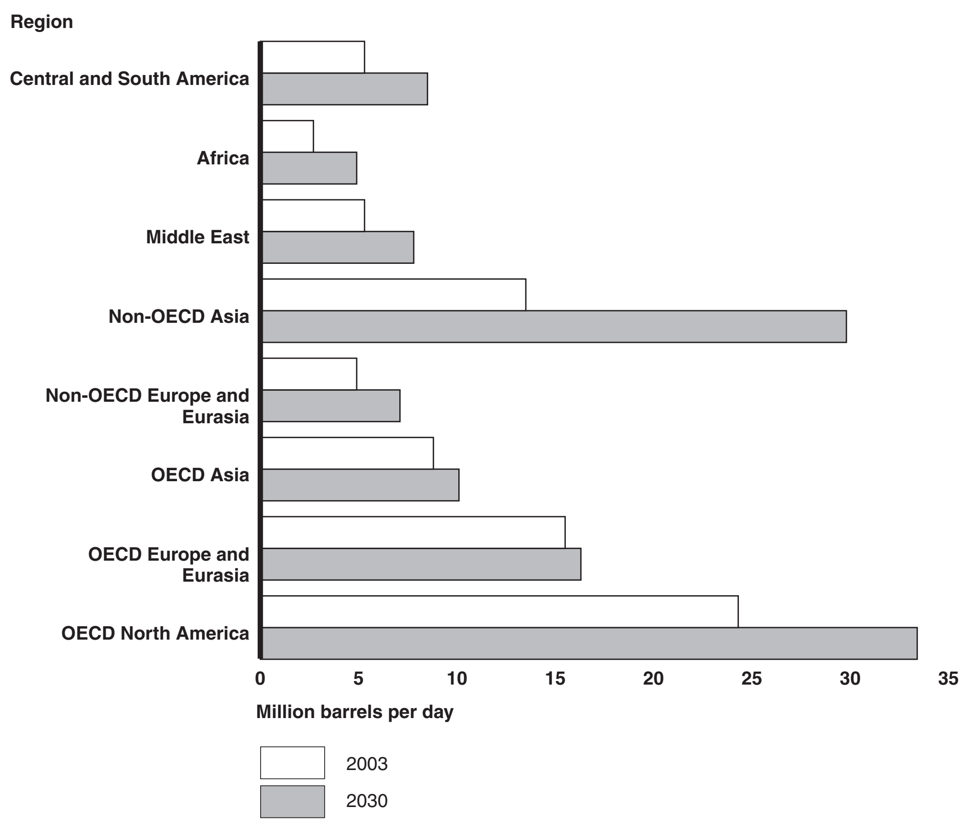
Source: International Energy Agency.

Note: This projection excludes production from nonconventional oil sources, such as Canadian oil sands.

Future World Demand for Oil Is Uncertain

Uncertainty about future demand for oil—which will influence how quickly the remaining oil is used—contributes to the uncertainty about the timing of peak oil production. EIA projects that oil will continue to be a major source of energy well into the future, with world consumption of petroleum products growing to 118 million barrels per day by 2030. Figure 11 shows world petroleum product consumption by region for 2003 and EIA's projections for 2030. As the figure shows, EIA projects that consumption will increase across all regions of the world, but members of the Organization for Economic Cooperation and Development (OECD) North America,[22] which includes the United States, and non-OECD Asia, which includes China and India, are the major drivers of this growth.

Figure 11: Daily World Oil Consumption, by Region for 2003 and Projected for 2030



Source: Energy Information Administration.

Future world oil demand will depend on such uncertain factors as world economic growth, future government policy, and consumer choices. Specifically:

- Economic growth drives demand for oil. For example, according to IEA, in 2003 the world experienced strong growth in oil consumption of 2.0 percent, with even stronger growth of 3.6 percent in 2004, from 79.8

[22]OECD is a group of 30 member countries sharing a commitment to democratic government and a market economy.

million barrels per day to 82.6 million barrels per day and China accounted for 30 percent of this increase, driven largely by China's almost 10 percent economic growth that year. EIA projects the Chinese economy will continue to grow, but factors such as the speed of reform of ineffective state-owned companies and the development of capital markets adds uncertainty to such projections and, as a result, to the level of future oil demand in China.

- Future government policy can also affect oil demand. For example, environmental concerns about gasoline's emissions of carbon dioxide, which is a greenhouse gas, may encourage future reductions in oil demand if these concerns are translated into policies that promote biofuels.
- Consumer choices about conservation also can affect oil demand and thereby influence the timing of a peak. For example, if U.S. consumers were to purchase more fuel-efficient vehicles in greater numbers, this could reduce future oil demand in the United States, potentially delaying a time at which oil supply is unable to keep pace with oil demand.

Such uncertainties that lead to changes in future oil demand ultimately make estimates of the timing of a peak uncertain, as is illustrated in an EIA study on peak oil.[23] Specifically, using future annual increases in world oil consumption, ranging from 0 percent, to represent no increase, to 3 percent, to represent a large increase, and out of the various scenarios examined, EIA estimated a window of up to 75 years for when the peak may occur.

Factors That Create Uncertainty about the Timing of the Peak Also Create Uncertainty about the Rate of Decline

Factors that create uncertainty about the timing of the peak—in particular, factors that affect oil exploration and production—also create uncertainty about the rate of production decline after the peak. For example, IEA reported that technology played a key role in slowing the decline and extending the life of oil production in the North Sea. Uncertainty about the rate of decline is illustrated in studies that estimate the timing of a peak. IEA, for example, estimates that this decline will range somewhere between 5 percent and 11 percent annually. Other studies assume the rate of decline in production after a peak will be the same as the rise in production that occurred before the peak. Another methodology,

[23] John H. Wood, Gary R. Long, and David F. Morehouse, *Long Term World Oil Supply Scenarios: The Future Is Neither as Bleak or Rosy as Some Assert*, Energy Information Administration, U.S. Department of Energy (2004).

employed by EIA, assumes that the resulting decline will actually be faster than the rise in production that occurred before the peak. The rate of decline after a peak is an important consideration because a decline that is more abrupt will likely have more adverse economic consequences than a decline that is less abrupt.

Alternative Transportation Technologies Face Challenges in Mitigating the Consequences of the Peak and Decline

In the United States, alternative transportation technologies have limited potential to mitigate the consequences of a peak and decline in oil production, at least in the near term, because they face many challenges that will take time and effort to overcome. If the peak and decline in oil production occur before these technologies are advanced enough to substantially offset the decline, the consequences could be severe. If the peak occurs in the more distant future, however, alternative technologies have a greater potential to mitigate the consequences.

Development and Adoption of Technologies to Displace Oil Will Take Time and Effort

Development and widespread adoption of the seven alternative fuels and advanced vehicle technologies we examined will take time, and significant challenges will have to be overcome, according to DOE. These technologies include ethanol, biodiesel, biomass gas-to-liquid, coal gas-to-liquid, natural gas and natural gas vehicles, advanced vehicle technologies, and hydrogen fuel cell vehicles.

Ethanol

Ethanol is an alcohol-based fuel produced by fermenting plant sugars. Currently, most ethanol in the United States is made from corn, but ethanol also can be made from cellulosic matter from a variety of agricultural products, including trees, grasses, and forestry residues. Corn ethanol has been used as an additive to gasoline for many years, but it is also available as a primary fuel, most commonly as a blended mix of 85 percent ethanol and 15 percent gasoline. As a primary fuel, corn ethanol is not currently available on a large national scale and federal agencies do not consider it to be cost-competitive with gasoline or diesel. The cost of corn feedstock, which accounts for approximately 75 percent of the production cost, is not projected to fall dramatically in the future, in part, because of competing demands for agricultural land use and competing uses for corn, primarily as livestock feed, according to DOE and USDA.

DOE and USDA project that more cellulosic ethanol could ultimately be produced than corn ethanol because cellulosic ethanol can be produced from a variety of feedstocks, but more fundamental reductions in production costs will be needed to make cellulosic ethanol commercially viable. Production of ethanol from cellulosic feedstocks is currently more costly than production of corn ethanol because the cellulosic material must first be broken down into fermentable sugars that can be converted into ethanol. The production costs associated with this additional processing would have to be reduced in order for cellulosic ethanol to be cost-competitive with gasoline at today's prices.

In addition, corn and cellulosic ethanol are more corrosive than gasoline, and the widespread commercialization of these fuels would require substantial retrofitting of the refueling infrastructure—pipelines, storage tanks, and filling stations. To store ethanol, gasoline stations may have to retrofit or replace their storage tanks, at an estimated cost of $100,000 per tank. DOE officials also reported that some private firms consider capital investment in ethanol refineries to be risky for significant investment, unless the future of alternative fuels becomes more certain. Finally, widespread use of ethanol would require a turnover in the vehicle fleet because most current vehicle engines cannot effectively burn ethanol in high concentrations.

Biodiesel

Biodiesel is a renewable fuel that has similar properties to petroleum diesel but can be produced from vegetable oils or animal fats. It is currently used in small quantities in the United States, but it is not cost-competitive with gasoline or diesel. The cost of biodiesel feedstocks—which in the United States largely consist of soybean oil—are the largest component of production costs. The price of soybean oil is not expected to decrease significantly in the future owing to competing demands from the food industry and from soap and detergent manufacturers. These competing demands, as well as the limited land available for the production of feedstocks, also are projected to limit biodiesel's capacity for large-volume production, according to DOE and USDA. As a result, experts believe that the total production capacity of biodiesel is ultimately limited compared with other alternative fuels.

Biomass Gas-to-Liquid

Biomass gas-to-liquid (biomass GTL) is a fuel produced from biomass feedstocks by gasifying the feedstocks into an intermediary product, referred to as syngas, before converting it into a diesel-like fuel. This fuel is not commercially produced, and a number of technological and economic challenges would need to be overcome for commercial viability. These challenges include identifying biomass feedstocks that are suitable for efficient conversion to a syngas and developing effective methods for preparing the biomass for conversion into a syngas. Furthermore, DOE researchers report that significant work remains to successfully gasify biomass feedstocks on a large enough scale to demonstrate commercial viability. In the absence of these developments, DOE reported that the costs of producing biomass GTL will be very high and significant uncertainty surrounding its ultimate commercial feasibility will exist.

Coal Gas-to-Liquid

Coal gas-to-liquid (coal GTL) is a fuel produced by gasifying coal into a syngas before being converted into a diesel-like fuel. This fuel is commercially produced outside the United States, but none of the production facilities are considered profitable. DOE reported that high capital investments—both in money and time—deter the commercial development of coal GTL in the United States. Specifically, DOE estimates that construction of a coal GTL conversion plant could cost up to $3.5 billion and would require at least 5 to 6 years to construct. Furthermore, potential investors are deterred from this investment because of the risks associated with the lengthy, uncertain, and costly regulatory process required to build such a facility. An expert at DOE also expressed concern that the infrastructure required to produce or transport coal may be insufficient. For example, the rail network for transporting western coal is already operating at full capacity and, owing to safety and environmental concerns, there is significant uncertainty about the feasibility of expanding the production capabilities of eastern coal mines. Coal GTL production also faces serious environmental concerns because of the carbon dioxide emitted during production. To mitigate the effect of coal GTL production, researchers are considering options for combining coal GTL production with underground injection of sequestered carbon dioxide to enhance oil recovery in aging oil fields.

Natural Gas and Natural Gas Vehicles

Natural gas is an alternative fuel that can be used as either a compressed natural gas or a liquefied natural gas. Natural gas vehicles are currently available in the United States, but their use is limited, and production has declined in the past few years. According to DOE, large-scale commercialization of natural gas vehicles is complicated by the widespread availability and lower cost of gasoline and diesel fuels. Furthermore, demand for natural gas in other markets, such as home heating and energy generation, presents substantial competitive risks to the natural gas vehicle industry. Production costs for natural gas vehicles are also higher than for conventional vehicles because of the incremental cost associated with a high-pressure natural gas tank. For example, light-duty natural gas vehicles can cost $1,500 to $6,000 more than comparable conventional vehicles, while heavy-duty natural gas vehicles cost $30,000 to $50,000 more than comparable conventional vehicles. Regarding infrastructure, retrofitting refueling stations so that they can accommodate natural gas could cost from $100,000 to $1 million per station, depending on the size, according to DOE. Although refueling at home can be an option for some natural gas vehicles, home refueling appliances are estimated to cost approximately $2,000 each.

Advanced Vehicle Technologies

Advanced vehicle technologies that we considered included lightweight materials and improvements to conventional engines that increase fuel economy, as well as hybrid vehicles and plug-in hybrid electric vehicles that use an electric motor/generator and a battery pack in conjunction with an internal combustion engine. Hybrid electric vehicles are commercially available in the United States, but these are not yet considered competitive with comparable conventional vehicles. DOE experts report that demand for such vehicles is predicated on their cost-competitiveness with comparable conventional vehicles. Hybrid electric vehicles, for example, cost $2,000 to $3,500 more to buy than comparable conventional vehicles and currently constitute around 1 percent of new vehicle registrations in the United States. In addition, electric batteries in hybrid electric vehicles face technical challenges associated with their performance and reliability when exposed to extreme temperatures or harsh automotive environments. Other advanced vehicle technologies, including advanced diesel engines and plug-in hybrids, are (1) in the very early stages of commercial release or are not yet commercially available and (2) face obstacles to large-scale commercialization. For example, advanced diesel engines present an environmental challenge because, despite their high fuel efficiency, they are not expected to meet future emission standards. Federal researchers are working to enable the engine to burn more cleanly, but these efforts are costly and face technical barriers. Plug-in hybrid electric vehicles are not yet commercially feasible because of cost, technical, and infrastructure challenges facing their development. For example, plug-in electric hybrids cost much more to produce than conventional vehicles, they require significant upgrades to home electrical systems to support their recharging, and researchers have yet to develop a plug-in electric with a range of more than 40 miles on battery power alone.

Hydrogen Fuel Cell Vehicles

A hydrogen fuel cell vehicle is powered by the electricity produced from an electrochemical reaction between hydrogen from a hydrogen-containing fuel and oxygen from the air. In the United States, these vehicles are still in the development stage, and making these vehicles commercially feasible presents a number of challenges. While a conventional gas engine costs $2,000 to $3,000 to produce, the stack of hydrogen fuel cells needed to power a vehicle costs $35,000 to produce. Furthermore, DOE researchers have yet to develop a method for feasibly storing hydrogen in a vehicle that allows a range of at least 300 miles before refueling. Fuel cell vehicles also are not yet able to last for 120,000 miles, which DOE believes to be the target for commercial viability. In addition, developing an infrastructure for distributing hydrogen—either through pipelines or through trucking—is expected to be complicated, costly, and time-consuming. Delivering hydrogen from a central source requires a large amount of energy and is considered costly and technically challenging. DOE has determined that decentralized production of hydrogen directly at filling stations could be a more viable approach than centralized production in some cases, but a cost-effective mechanism for converting energy sources into hydrogen at a filling station has yet to be developed.

More detailed information on these technologies is provided in appendix IV.

Consequences Could Be Severe If Alternative Technologies Are Not Available

Because development and widespread adoption of technologies to displace oil will take time and effort, an imminent peak and sharp decline in oil production could have severe consequences. The technologies we examined currently supply the equivalent of only about 1 percent of U.S. annual consumption of petroleum products, and DOE projects that even under optimistic scenarios, these technologies could displace only the equivalent of about 4 percent of annual projected U.S. consumption by around 2015. If the decline in oil production exceeded the ability of alternative technologies to displace oil, energy consumption would be constricted, and as consumers competed for increasingly scarce oil resources, oil prices would sharply increase. In this respect, the consequences could initially resemble those of past oil supply shocks, which have been associated with significant economic damage. For example, disruptions in oil supply associated with the Arab oil embargo of 1973-74 and the Iranian Revolution of 1978-79 caused unprecedented increases in oil prices and were associated with worldwide recessions. In addition, a number of studies we reviewed indicate that most of the U.S. recessions in the post-World War II era were preceded by oil supply shocks and the associated sudden rise in oil prices.

Ultimately, however, the consequences of a peak and permanent decline in oil production could be even more prolonged and severe than those of past oil supply shocks. Because the decline would be neither temporary nor reversible, the effects would continue until alternative transportation technologies to displace oil became available in sufficient quantities at comparable costs. Furthermore, because oil production could decline even more each year following a peak, the amount that would have to be replaced by alternatives could also increase year by year.

Consumer actions could help mitigate the consequences of a near-term peak and decline in oil production through demand-reducing behaviors such as carpooling; teleworking; and “eco-driving” measures, such as proper tire inflation and slower driving speeds. Clearly these energy savings come at some cost of convenience and productivity, and limited research has been done to estimate potential fuel savings associated with such efforts. However, DOE estimates that drivers could improve fuel economy between 7 and 23 percent by not exceeding speeds of 60 miles per hour, and IEA estimates that teleworking could reduce total fuel consumption in the U.S. and Canadian transportation sectors combined by between 1 and 4 percent, depending on whether teleworking is undertaken for 2 days per week or the full 5-day week, respectively.

If the peak occurs in the more distant future or the decline following a peak is less severe, alternative technologies have a greater potential to mitigate the consequences. DOE projects that the alternative technologies we examined have the potential to displace up to the equivalent of 34 percent of annual U.S. consumption of petroleum products in the 2025 through 2030 time frame. However, DOE also considers these projections optimistic—it assumes that sufficient time and effort are dedicated to the development of these technologies to overcome the challenges they face. More specifically, DOE assumes sustained high oil prices above $50 per barrel as a driving force. The level of effort dedicated to overcoming challenges to alternative technologies will depend in part on the price of oil, with higher oil prices creating incentives to develop alternatives. High oil prices also can spark consumer interest in alternatives that consume less oil. For example, new purchases of light trucks, SUVs, and minivans declined in 2005 and 2006, corresponding to a period of increasing gasoline prices. Gasoline demand has also grown slower in 2005 and 2006—0.95 and 1.43 percent, respectively—compared with the preceding decade, during which gasoline demand grew at an average rate of 1.81 percent. In the past, high oil prices have significantly affected oil consumption: U.S. consumption of oil fell by about 18 percent from 1979 to 1983, in part because U.S. consumers purchased more fuel-efficient vehicles in response to high oil prices.

While current high oil prices may encourage development and adoption of alternatives to oil, if high oil prices are not sustained, efforts to develop and adopt alternatives may fall by the wayside. The high oil prices and fears of running out of oil in the 1970s and early 1980s encouraged investments in alternative energy sources, including synthetic fuels made from coal, but when oil prices fell, investments in these alternatives became uneconomic. More recently, private sector interest in alternative fuels has increased, corresponding to the increase in oil prices, but uncertainty about future oil prices can be a barrier to investment in risky alternative fuels projects. Recent polling data also indicate that consumers' interest in fuel efficiency tends to increase as gasoline prices rise and decrease when gasoline prices fall.

Federal Agencies Do Not Have a Coordinated Strategy to Address Peak Oil Issues

Federal agency efforts that could contribute to reducing uncertainty about the timing of a peak in oil production or mitigating its consequences are spread across multiple agencies and are generally not focused explicitly on peak oil issues. Federal agency-sponsored studies have expressed a growing concern over the potential for a peak, and officials from key agencies have identified options for reducing the uncertainty about the timing of a peak in oil production and mitigating its consequences. However, there is no strategy for coordinating or prioritizing such efforts.

Federal Agencies Have Many Programs and Activities Related to Peak Oil Issues, but Peak Oil Generally Is Not the Main Focus of These Efforts

Federal agencies have programs and activities that could be directed to reduce uncertainty about the timing of a peak in oil production or to mitigate the consequences of such a peak. For example, with regard to reducing uncertainty, DOE provides information and analysis about global supply and demand for oil and develops projections about future trends. Specifically, DOE's EIA regularly surveys U.S. operators to gather data about U.S. oil reserves and compiles reserves data for foreign countries from other sources. In addition, EIA prepares both a domestic and international energy outlook, which includes projections for future oil supply and demand. As previously discussed, USGS provides estimates of oil resources that have the potential to add to reserves in the United States. Interior's Minerals Management Service also assesses oil resources in the offshore regions of the United States.

In addition, several agencies conduct activities to encourage development of alternative technologies that could help mitigate the consequences of a decline in oil production. For example, DOE promotes development of alternative fuels and advanced vehicle technologies that could reduce oil consumption in the transportation sector by funding research and development of new technologies. In addition, USDA encourages development of biomass-based alternative fuels, by collaborating with industry to identify and test the performance of potential biomass feedstocks and conducting research to evaluate the cost of producing biomass fuels. DOT provides funding to encourage development of bus fleets that run on alternative fuels, promote carpooling among consumers, and conduct outreach and education concerning telecommuting. In addition, DOT is responsible for setting fuel economy standards for automobiles and light trucks sold in the United States.

While these and other programs and activities could be used to reduce uncertainty about the timing of a peak in oil production and mitigate its consequences, agency officials we spoke with acknowledged that most of these efforts are not explicitly designed to do so. For example, DOE's activities related explicitly to peak oil issues have been limited to conducting, commissioning, or participating in studies and workshops.

Agencies Have Options to Reduce Uncertainty and Mitigate Consequences but Lack a Coordinated Strategy

Several federally sponsored studies we reviewed reflect a growing concern about peak oil and identify a need for action. For example:

- DOE has sponsored two studies.[24] A 2003 study highlighted the benefit of reducing the uncertainty surrounding the timing of a peak to mitigate its potentially severe global economic consequences. A 2005 study examined mitigating the consequences of a peak and concluded the following: "Timely, aggressive mitigation initiatives addressing both the supply and the demand sides of the issue will be required."
- While EIA's 2004 study of the timing of peak oil estimates that a peak might occur closer to 2050, EIA recognized that early preparation was important because of the long period required for widespread commercial production and adoption of new energy technologies.[25]

[24]David L. Greene, Janet L. Hopson, and Jai Li, *Running Out Of and Into Oil: Analyzing Global Oil Depletion and Transition Through 2050*, Oak Ridge National Laboratory, Department of Energy (2003); and Robert L. Hirsch, Roger Bezdek, and Robert Wendling, *Peaking of World Oil Production: Impacts, Mitigation, and Risk Management*, Science Applications International Corporation and Management Information Services Inc. (February 2005).

[25]John H. Wood, Gary R. Long, and David F. Morehouse, *Long Term World Oil Supply Scenarios: The Future Is Neither as Bleak or Rosy as Some Assert*, Energy Information Administration, U.S. Department of Energy (2004).

- In its 2005 study of energy use in the military,[26] the U.S. Army Corps of Engineers emphasized the need to develop alternative technologies and associated infrastructure before a peak and decline in oil production.

In addition, in response to growing peak oil concerns, DOE asked the National Petroleum Council to study peak oil issues. The study is expected to be completed by June 2007.

In light of these concerns, agency officials told us that it would be worthwhile to take additional steps to reduce the uncertainty about the timing of a peak in oil production. EIA believes it could reduce uncertainty surrounding the timing of peak oil production if it were to robustly extend the time horizon of its analysis and projection of global supply and demand for crude oil presented in its domestic and international energy outlooks. Currently, EIA's projections extend only to 2030, and officials believe that consideration of peak oil would require a longer horizon. Also, the international outlook is fairly limited, in part because EIA no longer conducts its detailed Foreign Energy Supply Assessment Program. EIA is seeking to restart this effort in fiscal year 2007. In addition, USGS officials told us that better and more complete information about global oil resources could be used to improve estimates by EIA of the timing of a peak. USGS officials said their estimates of global oil resources could be improved or expanded in the following four ways:

- Add information on certain regions—which USGS refers to as "frontier regions"—where little is known about oil resources.
- Add information on nonconventional resources outside the United States. USGS believes these resources will play a large role in future oil supply, and, therefore, accurate estimates of these resources should be included in any attempts to determine the timing of a peak.
- Calculate reserves growth by country. USGS considers this information important because of the political and investment conditions that differ by country and will affect future oil production and exploration.

[26] Donald F. Fournier and Eileen T. Westervelt, *Energy Trends and Their Implications for U.S. Army Installations*, U.S. Army Corps of Engineers, Engineer Research and Development Center, ERDC/CERL TR-05-21 (September 2005).

- Provide more complete information for all major oil-producing countries. USGS noted that its assessment has some “holes” where resources in major-producing countries have not yet been estimated completely.

In addition to these actions reducing the uncertainty about the timing of a peak, agency officials also told us that they could take additional steps to mitigate the consequences of a peak. For example, DOE officials reported that they could expand their efforts to encourage the development of alternative fuels and advanced vehicle technologies. These efforts could be expanded by conducting more demonstrations of new technologies, facilitating greater information sharing among key industry players, and increasing cost share opportunities with industry for research and development.[27] Agency officials told us such efforts can be essential to developing and encouraging the technologies.

Although there are many options to reduce the uncertainty about the timing of a peak or to mitigate its potential consequences, according to DOE, there is no formal strategy to coordinate and prioritize federal programs and activities dealing with peak oil issues—either within DOE or between DOE and other key agencies.

Conclusions

The prospect of a peak in oil production presents problems of global proportion whose consequences will depend critically on our preparedness. The consequences would be most dire if a peak occurred soon, without warning, and were followed by a sharp decline in oil production because alternative energy sources, particularly for transportation, are not yet available in large quantities. Such a peak would require sharp reductions in oil consumption, and the competition for increasingly scarce energy would drive up prices, possibly to unprecedented levels, causing severe economic damage. While these consequences would be felt globally, the United States, as the largest consumer of oil and one of the nations most heavily dependent on oil for transportation, may be especially vulnerable among the industrialized nations of the world.

[27]Experts we spoke with noted that it is important that the government not choose one viable alternative technology to the exclusion of another technology.

In the longer term, there are many possible alternatives to using oil, including using biofuels and improving automotive fuel efficiency, but these alternatives will require large investments, and in some cases, major changes in infrastructure or break-through technological advances. In the past, the private sector has responded to higher oil prices by investing in alternatives, and it is doing so now. Investment, however, is determined largely by price expectations, so unless high oil prices are sustained, we cannot expect private investment in alternatives to continue at current levels. If a peak were anticipated, oil prices would rise, signaling industry to increase efforts to develop alternatives and consumers of energy to conserve and look for more energy-efficient products.

Federal agencies have programs and activities that could be directed toward reducing uncertainty about the timing of a peak in oil production, and agency officials have stated the value in doing so. In addition, agency efforts to stimulate the development and adoption of alternatives to oil use could be increased if a peak in oil production were deemed imminent.

While public and private responses to an anticipated peak could mitigate the consequences significantly, federal agencies currently have no coordinated or well-defined strategy either to reduce uncertainty about the timing of a peak or to mitigate its consequences. This lack of a strategy makes it difficult to gauge the appropriate level of effort or resources to commit to alternatives to oil and puts the nation unnecessarily at risk.

Recommendation for Executive Action

While uncertainty about the timing of peak oil production is inevitable, reducing that uncertainty could help energy users and suppliers, as well as government policymakers, to act in ways that would mitigate the potentially adverse consequences. Therefore, we recommend that the Secretary of Energy take the lead, in coordination with other relevant agencies, to prioritize federal agency efforts and establish a strategy for addressing peak oil issues. At a minimum, such a strategy should seek to do the following:

- Monitor global supply and demand of oil with the intent of reducing uncertainty surrounding estimates of the timing of peak oil production. This effort should include improving the information available to estimate the amount of oil, conventional and nonconventional, remaining in the world as well as the future production and consumption of this oil, while extending the time horizon of the government's projections and analysis.

- Assess alternative technologies in light of predictions about the timing of peak oil production and periodically advise Congress on likely cost-effective areas where the government could assist the private sector with development and adoption of such technologies.

Agency Comments and Our Evaluation

We provided the Departments of Energy and the Interior with a draft of this report for their review and comment.

DOE generally agreed with our message and recommendations and made several clarifying and technical comments, which we addressed in the body of the report as appropriate. Appendix V contains a reproduction of DOE's letter and our detailed response to their comments. Specifically, DOE commented that the draft report did not make a distinction between a peak in conventional versus a peak in total (conventional and nonconventional) oil. We agree that we have not made this distinction, in part because the numerous studies of peak oil that we reviewed did not always make such a distinction. Furthermore, we do not believe a clear distinction between these two peak concepts is possible, in part because the definition of what is conventional oil versus nonconventional oil is not universally agreed on. However, the information we have reported regarding uncertainty about the timing of a peak applies to either peak oil concept.

DOE also commented that our use of certain technical phrases, including the distinction between heavy and extra-heavy oils and the distinction between oil consumption and demand, may be confusing to some readers, and we have made changes to the text to avoid such confusion. DOE commented that the draft report wrongly attributed environmental concerns to the use of enhanced oil recovery techniques, stating that the environmental community prefers such techniques on existing oil fields to exploration and development of new fields. We do not disagree that the environmental costs of these techniques may be smaller than for other activities and we have added text to express DOE's views on this matter. However, our point in listing the cost and environmental challenges of enhanced oil recovery techniques is that increasing oil production in the future could be more costly and more environmentally damaging than production of conventional oil, using primary production methods. For this reason we disagree with DOE's comment that we should remove the references to environmental challenges.

Finally, DOE pointed out that the draft report was primarily focused on transportation technologies that are used to power autonomous vehicles, and they stated that a broader set of technologies that could displace oil should be considered. We agree with their characterization of the draft report. We chose transportation technologies because transportation accounts for such a large part of U.S. oil consumption and because DOE and other agencies have numerous programs and activities dealing with technologies to displace oil in the transportation sector. We also agree that a broader set of technologies should be considered in the long run as potential ways to mitigate the consequences of a peak in oil production. We encourage DOE and other agencies to fully explore the options to displace oil as they implement our recommendations to develop a strategy to reduce the uncertainty surrounding the timing of a peak in oil production and advise Congress on cost-effective ways to mitigate the consequences.

Interior generally agreed with our message and recommendations in the draft report and made clarifying and technical comments, which we addressed in the body of the report as appropriate. Appendix VI contains a reproduction of Interior's letter and our detailed response to its comments. Specifically, Interior emphasized that it has a major role to play in estimating global oil resources, and that this effort should be made in conjunction with the efforts of DOE. We agree and encourage DOE to work in conjunction with Interior and other key agencies in establishing a strategy to coordinate and prioritize federal agency efforts to reduce the uncertainty surrounding the timing of a peak and to advise Congress on how best to mitigate consequences. Interior also commented that mitigating the consequences of a peak is outside their purview. We agree, and, in this report, we focus on examples of work that Interior could undertake to assist in reducing the uncertainty surrounding the estimates of global oil resources.

As agreed with your offices, unless you publicly announce the contents of this report earlier, we plan no further distribution of it until 30 days from the report date. At that time, we will send copies of this report to interested congressional committees, other Members of Congress, the Secretaries of Energy and the Interior, and other interested parties. We also will make copies available to others upon request. In addition, the report will be available at no charge on the GAO Web site at http://www.gao.gov.

Should you or your staffs need further information, please contact me at 202-512-3841 or wellsj@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made contributions to this report are listed in appendix VII.

Jim Wells
Director, Natural Resources and Environment

Appendix I: Scope and Methodology

To examine estimates of when oil production could peak, we reviewed key peak oil studies conducted by government agencies and oil industry experts. We limited our review to those studies that were published and excluded white papers or unpublished research. For studies that we cited in this report, we reviewed their estimate of the timing, methodology, and assumptions about the resource base to ensure that we properly represented the validity and reliability of their results and conclusions. We also consulted with federal government agencies and oil companies, as well as academic and research organizations, to identify the uncertainties associated with the timing of a peak.

As part of our examination of the timing of peak oil production, we assessed other factors that could affect oil exploration and production. Specifically, we examined the challenges facing future technologies that could enhance the global production of oil, including technologies for increasing recovery from conventional reserves as well as technologies for producing nonconventional oil. To examine these technologies, we met with experts at the Department of Energy's (DOE) National Energy Technology Laboratory, and synthesized information provided by these experts.

In addition, we examined political and investment risks associated with global oil exploration and production using Global Insight's Global Risk Service. For each country, Global Insight's country risk analyst estimates the subjective probability of 15 discrete events for political risk, and 22 discrete events for investment risk in the upstream oil and gas sectors. The probability is estimated for the next 5 years. Senior analysts then meet to review the scores to ensure cross-country consistency. The summary score is derived by weighting different groups of factors and then summing across the groups. For political risk, external and internal political risks are the two groups of factors. For investment risk in the oil and gas sectors, the factors are: investment/maintenance risk, input risk, production risk, sales risk, and revenue/repatriation risk. We compared political and investment risk with *Oil and Gas Journal* oil reserves estimates. *Oil and Gas Journal* reserves estimates are limited by the fact that they are not independently verified by the publishers and are based on surveys filled out by the countries. Because most countries do not reassess annually, some estimates in this survey do not change each year. We divided the countries into risk categories of low, medium, and high on the basis of quartiles and natural break points in the data. To obtain the percentage of reserves held by public companies and by national oil companies, we used the *Petroleum Intelligence Weekly* list of top 50 companies worldwide. The *Petroleum Intelligence Weekly* data are limited by reliance on company reports and other information sources provided by companies and the generation of estimates for those companies that do not release regular or complete reports. Estimates were created for most of the state-owned oil companies in figure 9 of this report. The limitations of these data reflect the uncertainty in estimates of the amount of oil in the ground, and our report does not rely on precise estimates of oil reserves but rather on the uncertainty about the amount of oil throughout the world and the challenges to exploration and production of oil. Therefore, we found these data to be sufficiently reliable for the purposes of our report. We also spoke with officials at the Securities and Exchange Commission and with DOE as well as experts in academia and industry. In addition, we reviewed documents from the Department of the Interior and the International Energy Agency (IEA).

To assess the potential for transportation technologies to mitigate the consequences of a peak and decline in oil production, we examined options to develop alternative fuels and technologies to reduce energy consumption in the transportation sector. In particular, we focused on technologies that would affect automobiles and light trucks. We consulted with experts to devise a list of key technologies in these areas and then reviewed DOE programs and activities related to developing these technologies. To assess alternative fuels and advanced vehicle technologies, we met with various experts at DOE, including representatives from the National Energy Technology Laboratory and the National Renewable Energy Laboratory, and reviewed information provided by officials from various offices at DOE. In addition, we spoke with officials from the U.S. Department of Agriculture (USDA) and the Department of Transportation regarding the development of these technologies in the United States. We did not attempt to comprehensively list all technologies or to conduct a governmentwide review of all programs, and we limited our scope to what government officials at key federal agencies know about the status of these technologies in the United States. In addition, we did not conduct a global assessment of transportation technologies. We reviewed numerous studies on the relationship between oil and the global economy and, in particular, on the experiences of past oil price shocks.

To identify federal government activities that could address peak oil production issues, we spoke with officials at DOE and the United States Geological Survey (USGS), and gathered information on federal programs and policies that could affect uncertainty about the timing of peak oil production and the development of alternative transportation technologies. To gain further insights into the federal role and other issues surrounding peak oil production, we convened an expert panel in Washington, D.C., in conjunction with the National Research Council of the National Academy of Sciences. On May 5, 2006, these experts commented on the potential economic consequences of a transition away from conventional oil; factors that could affect the severity of the consequences; and what the federal role should be in preparing for or mitigating the consequences, among other things. We recorded and transcribed the meeting to ensure that we accurately captured the panel members' statements.

The following 13 experts served on the panel:

- Stephen Brown, Director of Energy Economics and Microeconomic Policy Analysis, Federal Reserve Bank of Dallas
- David Greene, Corporate Fellow, Oak Ridge National Laboratory
- Howard Gruenspecht, Deputy Administrator, Energy Information Administration
- James Hamilton, Professor of Economics, University of California, San Diego
- Robert Hirsch, Senior Energy Program Advisor, SAIC
- Hillard G. Huntington, Executive Director Energy Modeling Forum, Stanford University
- James Katzer, Visiting Scholar, Massachusetts Institute of Technology (MIT), and Manager (retired), Strategic Planning and Performance Analysis, ExxonMobil Research and Engineering Company
- Robert Kaufmann, Professor, Center for Energy & Environmental Studies, Boston University
- Paul Leiby, Oak Ridge National Laboratory
- Nicola Pochettino, Senior Energy Analyst, Economic Analysis Division, International Energy Agency
- Edward Porter, Research Manager, American Petroleum Institute
- James Smith, Maguire Chair of Oil and Gas Management, Edwin L. Cox School of Business, Southern Methodist University

- James Sweeney, Professor, Management Science and Engineering, Stanford University

Appendix II: Key Peak Oil Studies

This appendix lists the studies cited in figure 5 of this report.

(a) L.F. Ivanhoe. " Updated Hubbert Curves Analyze World Oil Supply." *World Oil.* Vol. 217 (November 1996): 91-94.

(b) Albert A. Bartlett. " An Analysis of U.S. and World Oil Production Patterns Using Hubbert-Style Curves." *Mathematical Geology.* Vol. 32, no.1 (2000).

(c) Kenneth S. Deffeyes. " World's Oil Production Peak Reckoned in Near Future." *Oil and Gas Journal.* November 11, 2002.

(d) Volvo. *Future Fuels for Commercial Vehicles.* 2005.

(e) A.M. Samsam Bakhtiari. " World Oil Production Capacity Model Suggests Output Peak by 2006-2007." *Oil and Gas Journal.* April 26, 2004.

(f) Richard C. Duncan. " Peak Oil Production and the Road to the Olduvai Gorge." *Pardee Keynote Symposia.* Geological Society of America, Summit 2000.

(g) David L. Greene, Janet L. Hopson, and Jai Li. *Running Out Of and Into Oil: Analyzing Global Oil Depletion and Transition Through* 2050. Oak Ridge National Laboratory, Department of Energy, October 2003.

(h) C.J. Campbell. " Industry Urged to Watch for Regular Oil Production Peaks, Depletion Signals." *Oil and Gas Journal.* July 14, 2003.

(i) Merril Lynch. *Oil Supply Analysis.* October 2005.

(j) Ministére de l'Economie Des Finances et de l'Industrie. *L'industrie pétrolière en 2004.* 2005.

(k) International Energy Agency. *World Energy Outlook 2004.* Paris France: 101-103.

(l) Jean Laherrère. *Future Oil Supplies.* Seminar Center of Energy Conversion, Zurich: 2003.

(m) Peter Gerling, Hilmar Remple, Ulrich Schwartz-Schampera, and Thomas Thielemann. *Reserves, Resources and Availability of Energy Resources.* Federal Institute for Geosciences and Natural Resources, Hanover, Germany: 2004.

(n) John D. Edwards. " Crude Oil and Alternative Energy Production Forecasts for the Twenty-First Century: The End of the Hydrocarbon Era." *American Association of Petroleum Geologists Bulletin*. Vol. 81, no. 8 (August 1997).

(o) Cambridge Energy Research Associates, Inc. *Worldwide Liquids Capacity Outlook to 2010, Tight Supply or Excess of Riches.* May 2005.

(p) John H. Wood, Gary R. Long and David F. Morehouse. *Long Term World Oil Supply Scenarios.* Energy Information Administration: 2004.

(q) Total. *Sharing Our Energies: Corporate Social Responsibility Report 2004.*

(r) Shell International. *Energy Needs, Choices and Possibilities: Scenarios to 2050.* Global Business Environment: 2001.

(s) Directorate-General for Research Energy. *World Energy, Technology and Climate Policy Outlook: WETO 2030.* European Commission, EUR 20366: 2003.

(t) Exxon Mobil. *The Outlook for Energy: A View to 2030.* Corporate Planning. Washington, D.C.: November 2005.

(u) Harry W. Parker. " Demand, Supply Will Determine When World Oil Output Peaks." *Oil and Gas Journal*. February 25, 2002.

(v) M.A. Adelman and Michael C. Lynch. " Fixed View of Resource Limits Creates Undue Pessimism." *Oil and Gas Journal.* April 7, 1997.

Appendix III: Key Technologies to Enhance the Supply of Oil

This appendix contains brief profiles of technologies that could enhance the future supply of oil. This includes technologies for (1) increasing the rate of recovery from proven oil reserves using enhanced oil recovery; (2) producing oil from deepwater and ultra-deepwater reservoirs; and (3) producing nonconventional oil, such as oil sands and oil shale. For each technology, we provide a short description, followed by selected information on the key costs, potential production, readiness, key challenges, and current federal involvement. Although some of these technologies are in production or development throughout the world, the following profiles primarily focus on the development of these technologies in the United States.

Enhanced Oil Recovery

Enhanced oil recovery (EOR) refers to the third stage of oil production, whereby sophisticated techniques are used to recover remaining oil from reservoirs that have otherwise been exhausted through primary and secondary recovery methods. During EOR, heat (such as steam), gases (such as carbon dioxide (CO_2)), or chemicals are injected into the reservoir to improve fluid flow. Thermal and gas injection techniques account for almost all EOR activity in the United States, with CO_2 injection being the technique that is currently attracting the most commercial interest. In the United States, EOR methods are currently being applied in a variety of regions, although most CO_2 EOR occurs in the Permian Basin in Texas. Most EOR efforts in the United States are currently managed by small, independent operators. Globally, EOR has been introduced in a number of countries, but North America is estimated to represent over half of all global EOR production.

Key Costs

- Costs associated with EOR production vary by reservoir, but reported marginal costs for oil recovery using EOR can range from $1.42 per barrel to $30 per barrel.
- Key capital costs include new drills, reworking of existing drills, reconfiguring gathering systems, and modification of the injection plant and other surface facilities.

Potential Production

- EOR currently contributes approximately 12 percent to the U.S. production of oil.

- EOR is projected to increase average recovery rates in reservoirs from 30 percent to 50 percent.
- Upper-end estimates of EOR's future recovery potential in the United States include the following: 1.0 million barrels per day by 2015 and 2.5 million barrels per day by 2025.

Readiness

- Thermal, gas, and chemical injection technologies are currently commercially available.
- Key areas for further development exist, including sweep efficiency and water shut-off methods.

Key Challenges

- Key challenges facing the development of EOR include the following: (1) a lack of industry-accepted, economical fluid injection systems; (2) a reliance on out-of-date practices and limited data due to lack of familiarity with state-of-the-art imaging and reluctance to risk investment in technologies; and (3) unwillingness on the part of some operators to assume the risks associated with EOR.

Current Federal Involvement

- DOE is involved in several industry consortia and individual programs, designed to develop EOR, including conducting research and development and educating small producers about EOR.

Deepwater and Ultra-Deepwater Drilling

Deepwater drilling refers to offshore drilling for oil in depths of water between 1,000 and 5,000 feet, while ultra-deepwater drilling refers to offshore drilling in depths of water between 5,000 and 10,000 feet, according to DOE. The department reported that oil production at these depths involves a number of differences over shallow water drilling, such as drills that operate in extreme conditions, pipes that withstand deepwater ocean currents over long distances, and floating rigs as opposed to fixed rigs. The primary region for domestic deepwater drilling is the Gulf of Mexico, where deepwater drilling has become a major focus in recent years, particularly as near-shore oil production in shallow water has been declining. Globally, deepwater drilling occurs offshore in many locations, including Africa, Asia, and Latin America.

Key Costs

- Costs vary by rig type, but the three key components of cost for deepwater and ultra-deepwater drilling include the following: (1) the daily vessel rental rate, (2) materials, and (3) drilling services.

- The average market rate for Gulf of Mexico rigs can range from $210,000 per day to $300,000 per day.

- Overall, the projected marginal costs of deepwater drilling range from 3.0 to 4.5 times the cost of shallow water drilling.

Potential Production

- Current deepwater production in the Gulf of Mexico is estimated at 1.3 million barrels per day.

- Deepwater production in the Gulf of Mexico is projected to exceed 2 million barrels per day in the next 10 years.

Readiness

- Commercial deepwater drilling at depths of more than 1,000 feet in the Gulf of Mexico has been under way since the mid-1970s.

- Companies are currently exploring prospects for drilling in depths of more than 5,000 feet, and since 2001, 11 discoveries of ultra-deepwater wells at depths of more than 7,000 feet have been announced.

Key Challenges

- Examples of some of the key challenges facing the development of deepwater and ultra-deepwater drilling include the following: (1) rig issues, such as finding ways to adapt and use lower-cost rigs and improving the ability to moor vessels in deepwater; (2) drilling equipment reliability at high pressures and temperatures; and (3) reducing the costs of drilling and producing at deepwater and ultra-deepwater depths.

Current Federal Involvement

- DOE is not directly involved in deepwater and ultra-deepwater drilling, but it does fund projects that could impact such drilling.

- The Energy Policy Act of 2005 authorized some funding for research and development of alternative oil and gas activities, including deepwater drilling.

Oil Sands

Oil sands are deposits of bitumen, a thick, sticky form of crude oil, which is so heavy and viscous that it will not flow unless heated or diluted with lighter hydrocarbons. It must be rigorously treated to convert it into an upgraded crude oil before it can be used by refineries to produce gasoline and diesel fuels. While conventional crude flows naturally or is pumped from the ground, oil sands must be mined or recovered "in-situ," or in place. During oil sands mining, approximately 2 tons of oil sands must be dug up, moved, and processed to produce 1 barrel of oil. During in-situ recovery, heat, solvents, or gases are used to produce the oil from oil sands buried too deeply to mine. The largest deposit of oil sands globally is found in Alberta, Canada—accounting for at least 85 percent of the world's oil sands reserves—although DOE reported that deposits of oil sands can also be found in the United States in Alabama, Alaska, California, Texas, and Utah.

Key Costs

- Commercial Canadian oil sands are being produced at $18 to $22 per barrel.
- Key infrastructure costs to support oil sands production in the United States would include construction of roads, pipelines, water, and energy production facilities.

Potential Production

- The 2005 production of Canadian oil sands yielded 1.6 million barrels of oil per day and production is projected to grow to as much as 3.5 million barrels per day by 2030.
- Current U.S. production of oil sands currently yields less than 175,000 barrels per year, and future production of U.S. oil sands will depend on the industry's investment decisions.

Readiness

- Production of Canadian oil sands is currently in the commercial phase.

- U.S. oil sands production is only in the demonstration phase, and adapting Canadian technologies to the characteristics of U.S. oil sands will require time.

Key Challenges

- Examples of key challenges facing the development of oil sands include the following: (1) evaluating and alleviating environmental impacts, particularly concerning water consumption; (2) accessing the federal lands on which most of the U.S. oil sands are located; (3) addressing the increased demand on roads, schools, and other infrastructure that would result from the need to construct production facilities in some remote areas of the west; and (4) addressing the increased need for natural gas, electricity, and water for production.

Current Federal Involvement

- There are currently no federal programs to develop the U.S. oil sands resource, although the Energy Policy Act of 2005 called for the establishment of a number of policies and actions to encourage the development of unconventional oils in the United States, including oil sands.
- The Bureau of Land Management, which manages most of the federal lands where oil sands occur, maintains an oil sands leasing program.

Heavy and Extra-Heavy Oils

Heavy and extra-heavy oils are dense, viscous oils that generally require advanced production technologies, such as EOR, and substantial processing to be converted into petroleum products. Heavy and extra-heavy oils differ in their viscosities and other physical properties, but advanced recovery techniques like EOR are required for both types of oil. Heavy and extra-heavy oil reserves occur in many regions around the world, with the Orinoco Oil Belt in Eastern Venezuela comprising almost 90 percent of the total extra-heavy oil in the world. In the United States, heavy oil reserves are primarily found in Alaska, California, and Wyoming, and some commercial heavy oil production is occurring domestically.

Key Costs

- The cost of producing heavy and extra-heavy oil is greater than the cost of producing conventional oil, due to, among other things, higher drilling, refining, and transporting costs.

Potential Production

- The 2005 Venezuelan extra-heavy oil production was estimated to be 600,000 barrels of oil per day and is projected to at least sustain this production rate through 2030.
- In 2004, production of heavy oil in California was 474,000 barrels per day. In December 2005, heavy oil production in Alaska was 42,500 barrels per day, but some project Alaskan production to increase to 100,000 barrels per day in 5 years.

Readiness

- Extra-heavy oil production is in the commercial phase in Venezuela.
- Heavy oil production technologies are currently commercially available and employed in the United States.

Key Challenges

- Development of the heavy oil resource in the United States faces environmental, economic, technical, permitting, and access-to-skilled-labor challenges.

Current Federal Involvement

- There has not been a specific DOE program focused on heavy oil, as most of the research and developments have been handled under the general research umbrella for EOR.
- The Energy Policy Act of 2005 called for an update of the 1987 technical and economic assessment of heavy oil resources in the United States.

Oil Shale

Oil shale refers to sedimentary rock that contains solid bituminous materials that are released as petroleum-like liquids when the rock is heated. To obtain oil from oil shale, the shale must be heated and the resultant liquid must be captured, in a process referred to as “retorting.” Oil shale can be produced by mining followed by surface retorting or by in-situ retorting. The largest known oil shale deposits in the world are in the Green River Formation, which covers portions of Colorado, Utah, and Wyoming. Estimates of the oil resource in place range from 1.5 trillion to 1.8 trillion barrels, but not all of the resource is recoverable. In addition to the Green River Formation, Australia and Morocco are believed to have oil shale resources. At the present time, a RAND study reported there are economic and technical concerns associated with the development of oil shale in the United States, such that there is uncertainty regarding whether industry will ultimately invest in commercial development of the resource.

Key Costs

- On the basis of currently available information, oil shale cannot compete with conventional oil production.
- At the present time, and given current technologies and information, Shell Oil reports that it may be able to produce oil shale for $25 to $30 per barrel.
- Infrastructure costs for oil shale production include the following: additional electricity, water, and transportation needs. A RAND study expects a dedicated power plant for the production of oil shale to exceed $1 billion.

Potential Production

- The Green River Basin is believed to have the potential to produce 3 million to 5 million barrels per day for hundreds of years.
- Given the current state of the technology and associated challenges, however, it is possible that 10 years from now, the oil shale resource could be producing 0.5 million to 1.0 million barrels per day.

Readiness

- Oil shale is not presently in the research and development stage.
- Shell Oil has the most advanced concept for oil shale, and it does not anticipate making a decision regarding whether to attempt commercialization until 2010.

Key Challenges

- Examples of key challenges facing the development of oil shale include the following: (1) controlling and monitoring groundwater, (2) permitting and emissions concerns associated with new power generation facilities, (3) reducing overall operating costs, (4) water consumption, and (5) land disturbance and reclamation.

Current Federal Involvement

- The Energy Policy Act of 2005 called for the establishment of a number of policies and actions to encourage the development of unconventional oils in the United States, including oil shale.

Appendix IV: Key Technologies to Displace Oil Consumption in the Transportation Sector

This appendix contains brief profiles of key technologies that could displace U.S. oil consumption in the transportation sector. These technologies include alternative fuels to supplement or substitute for gasoline as well as advanced vehicle technologies to increase fuel efficiency. For each technology, on the basis of information provided by federal experts, we provide a short description, followed by selected information on the costs, potential production or displacement of oil, readiness, key challenges, and current federal involvement. Although some of these technologies are in production or development throughout the world, the following profiles primarily focus on the development of these technologies in the United States.

Ethanol

Ethanol is a grain alcohol-based, alternative fuel made by fermenting plant sugars. It can be made from many agricultural products and food wastes if they contain sugar, starch, or cellulose, which can then be fermented and distilled into ethanol. Pure ethanol is rarely used for transportation; instead, it is usually mixed with gasoline. The most popular blend for light-duty vehicles is E85, which is 85 percent ethanol and 15 percent gasoline. The technology for producing ethanol, at least from certain feedstocks, is generally well established, and ethanol is currently produced in many countries around the world. In Brazil, the world's largest producer, ethanol is produced from sugar cane. In the United States, more than 90 percent of ethanol is produced from corn, but efforts are under way to develop methods for producing ethanol from other biomass materials, including forest trimmings and agricultural residues (cellulosic ethanol). Currently, corn ethanol is primarily produced and used across the Midwest.

Key Costs

- The current cost of producing ethanol from corn is between \$0.90 to \$1.25 per gallon, depending on the plant size, transportation cost for the corn, and the type of fuel used to provide steam and other energy needs for the plant.
- The projected cost of producing ethanol from biomass is expected to drop significantly to about \$1.07 per gallon by 2012.
- The current cost of producing of ethanol from biomass is not cost competitive, but by 2012 it is projected to be about \$1.07 per gallon.
- Key infrastructure costs associated with ethanol include retrofitting refueling stations to accommodate E85 (estimated at between \$30,000 and

$100,000) and constructing or modifying pipelines to transport ethanol.

Potential Production

- The 2005 production of ethanol in the United States was approximately 4 billion gallons. By 2014-15, corn ethanol production is expected to peak at approximately 9 billion to 18 billion gallons annually.
- Assuming success with cellulosic ethanol technologies, experts project cellulosic ethanol production levels of over 60 billion gallons by 2025-30.

Readiness

- Corn ethanol is commercially produced today and continues to expand rapidly.
- Cellulosic ethanol is in the demonstration phase, but it is projected to be demonstrated by 2010.

Key Challenges

- For corn ethanol, key challenges include the necessary infrastructure changes to support ethanol distribution and the ability and willingness of consumers to adapt to ethanol.
- For cellulosic ethanol, several technical challenges still remain, including improving the enzymatic pretreatment, fermentation, and process integration.
- For cellulosic ethanol, economic challenges are high feedstock and production costs and the initial capital investment.

Current Federal Involvement

- The federal government is currently involved in numerous efforts to develop ethanol. Several federal agencies collaborate with industry to accelerate the technologies, reduce the cost of the technologies, and assist in developing the infrastructure.

Biodiesel

Biodiesel is a renewable fuel that has similar properties to petroleum diesel, but it can be produced from vegetable oils or animal fats. Like petroleum diesel, biodiesel operates in compression-ignition engines. Blends of up to 20 percent biodiesel (B20) can be used in nearly all diesel equipment and are compatible with most storage and distribution equipment. These low-level blends generally do not require any engine modifications. Higher blends and 100 percent biodiesel (B100) may be used in some engines with little or no modification, although transportation and storage of B100 requires special management. Biodiesel is currently produced and used as a transportation fuel around the world. In the United States, the biodiesel industry is small but growing rapidly, and refueling stations with biodiesel can be found across the country.

Key Costs

- The current wholesale cost of pure biodiesel (B100) ranges from about \$2.90 to \$3.20 per gallon, although recent sales have been reported at \$2.75 per gallon.
- To date, there has been limited evaluation of the projected infrastructure costs required for biodiesel. However, it is acknowledged that there are infrastructure costs associated with installation of manufacturing capacity, distribution, and blending of the biodiesel.

Potential Production

- In 2005, U.S. production of biodiesel was 75 million gallons, and DOE projects about 3.6 billion gallons per year by 2015.
- Under a more speculative scenario requiring major changes in land use and price supports, experts project it would be possible to produce 10 billion gallons of biodiesel per year.

Readiness

- While biodiesel is commercially available, in many ways it is still in development and demonstration. Key areas of focus for development and demonstration include quality, warranty coverage, and impact of air pollutant emissions and compatibility with advanced control systems.
- Experts project that, with adequate resources, key remaining developments could be resolved in the next 5 years.

Key Challenges

- Initial capital costs are significant and the technical learning curve is steep, which deters many potential investors.

- Economic challenges are significant for biodiesel. In the absence of the $1 per gallon excise tax, biodiesel would not likely be cost-competitive.

Current Federal Involvement

- DOE is currently collaborating with the biodiesel and automobile industries in funding research and development efforts on biodiesel use, and USDA is conducting research on feedstocks.

Coal and Biomass Gas-to-Liquids

Gas-to-liquid (GTL) alternatives include the production of liquid fuels from a variety of feedstocks, via the Fisher-Tropsch process. In the Fischer-Tropsch process, feedstocks such as coal and biomass are converted into a syngas, before the gas is converted into a diesel-like fuel. The diesel-like fuel is low in toxicity and is virtually interchangeable with conventional diesel fuels. Although these technologies have been available in some form since the 1920s, and coal GTL was used heavily by the German military during World War II, GTL technologies are not widely used today. Currently, there is no commercial production of biomass GTL and the only commercial production of coal GTL occurs in South Africa, where the Sasol Corporation currently produces 150,000 barrels of fuel from coal per day. Extensive research and development, however, is currently under way to further develop this technology because automakers consider GTL fuels viable alternatives to oil without compromising fuel efficiency or requiring major infrastructure changes.

Key Costs

- *Coal.* Construction of a precommercial coal GTL plant is estimated at $1.7 billion, while construction of a commercial coal GTL is estimated at $3.5 billion.
- *Biomass.* Potential costs associated with biomass GTL are uncertain, given the early stage of the technology.
- Infrastructure costs associated with both biomass and coal GTLs are expected to be substantial, given the necessary modifications to pipelines, refueling centers, and storage facilities.

Potential Production

- *Coal.* Experts project that, at most, 80,000 barrels per day could be produced by 2015 and 1.7 million barrels per day by 2030.

- *Biomass.* Some experts project biomass GTL to have the potential to produce up to approximately 1.4 million barrels-of-oil-equivalent per day by 2030.

Readiness

- *Coal.* Coal GTL is commercially available in South Africa, but the technology has not yet been commercially adopted in the United States.
- *Biomass.* Biomass GTL is currently in research and development, nearing the demonstration stage. Experts project that biomass GTL production could be demonstrated at the pilot scale by 2012.

Key Challenges

- *Coal.* Key challenges facing coal GTL include technology integration, for example integrating various processes with combined cycle turbine and CO_2 capture operations, and market risk.
- *Biomass.* The challenges are mostly technical in nature, for example, pretreatment of biomass feedstocks, identification of high-efficiency feedstocks, improving cleanliness of the syngas, and process integration.

Current Federal Involvement

- *Coal.* DOE does not receive any direct funding for coal GTL, but funding for other programs indirectly supports and benefits some coal GTL research.
- *Biomass.* DOE funds some biomass conversion research.

Natural Gas

Natural gas is an alternative fuel that can be used as either heavy-duty compressed natural gas or liquefied natural gas to power natural gas vehicles. These vehicles require pressurized tanks, which have been designed to withstand severe impact, high external temperatures, and environmental exposure. Natural gas can be used by either retrofitting an existing gasoline or diesel engine or purchasing a natural gas vehicle. Natural gas vehicles are in use in many countries, totaling more than 5 million natural gas vehicles and over 9,000 refueling stations. The United States has about 130,000 natural gas vehicles and 1,340 refueling stations.

Key Costs

- Light-duty natural gas vehicles are estimated to cost an additional $1,000 per vehicle.
- Heavy-duty natural gas vehicles are estimated to cost an additional $10,000 to $30,000 per vehicle.
- Natural gas refueling stations are estimated to cost $100,000 to $1 million to build, while home fueling appliances cost approximately $2,000 per year.

Potential Production

- Currently, natural gas vehicles displace approximately 65 million gallons of diesel fuel per year.
- There is a potential niche market in heavy-duty vehicles for natural gas, which could displace 1,500 million gallons of gasoline per year.

Readiness

- Natural gas vehicles are commercially available now, but their overall use is limited on a national scale and production has been declining in recent years.
- Heavy-duty natural gas vehicles are in the final stages of research and development.

Key Challenges

- Examples of some key challenges facing the adoption of natural gas vehicles include the following: (1) the higher cost of high-pressure fuel tanks for consumers, (2) the costly upgrades to the existing refueling infrastructure, and (3) the availability and cost of natural gas.

Current Federal Involvement

- There is currently no federal funding or research focusing on natural gas vehicles.

Advanced Vehicle Technologies

Vehicle technologies encompass several different efforts to reduce vehicles' oil consumption. Increasing the efficiency of the internal combustion engine, specifically advanced diesel engines, is considered a first step toward other engine technologies. For example, researchers are working to improve the emissions profile of advanced diesel engines through techniques such as low-temperature combustion, which would enable the engine to burn more cleanly so that emissions control at the tailpipe is less burdensome. Another set of technologies are hybrid electric and plug-in hybrid electric vehicles. Hybrid vehicles use a battery alongside the internal combustion engine to facilitate the capture of braking energy as well as to provide propulsion, while plug-in hybrids use a different battery and can be powered by battery alone for an extended period. Researchers are examining how to build longer-lasting and less-expensive batteries for hybrid and plug-in hybrid vehicles. Finally, a range of ongoing work is attempting to improve the efficiency of conventional vehicles. For example, lightweight materials have the potential to improve efficiency by reducing vehicle weight. Oil consumption can also be cut by reducing the rolling resistance of tires, increasing the efficiency of transmission technologies that move the energy from the engine to the tires, and improving how power is managed within the vehicle.

Key Costs

- *Advanced diesel engines.* DOE does not have information on the potential cost of this technology. Officials told us that this information is proprietary.

- *Hybrid electric and plug-in hybrid vehicles.* DOE officials told us that these vehicles can cost several thousand dollars more than conventional vehicles, although some of the incremental cost in hybrid vehicles currently on the market may be related to additional amenities, rather than the hybrid technology.

- *Lightweight materials.* DOE officials told us that lightweight carbon fiber materials currently cost approximately $12 to $15 per pound, and that their goal is to reduce this cost to $3 to $5 per pound. Information was not available on costs associated with other technologies to improve conventional vehicle efficiency.

Potential Displacement of Oil

- DOE estimates that the oil savings that would result from its vehicle technology efforts, including research on internal combustion engines, hybrids, and other vehicle efficiency measures, is 20,000 barrels per day by

2010, up to 1.07 million barrels per day by 2025.

- DOE was not able to estimate oil savings for plug-in hybrids for fiscal year 2007.

Readiness

- *Advanced diesel engines.* Low-temperature combustion that would reduce the emissions burden of diesel engines is under research and development.

- *Hybrid electric and plug-in hybrid electric vehicles.* Hybrid electric vehicles are currently on the market, although research continues on longer-lasting, less expensive batteries for both hybrid and plug-in hybrid electric vehicles. DOE's goal is to have plug-in hybrids commercially available by 2014, although officials considered this an aggressive goal.

- *Lightweight vehicle materials.* Lightweight materials, such as aluminum, magnesium, and polymer composites, have made inroads into vehicle manufacturing. However, research and development are still under way on reducing the costs of these materials. By 2012, DOE aims to make the life-cycle costs of glass- and carbon-fiber-reinforced composites, along with several other lightweight materials, comparable to the costs for conventional steel.

Key Challenges

- *Advanced diesel engines.* Reducing the emissions of nitrogen oxides and particulate matter to meet government requirements is a key challenge for the diesel engine combustion process. Emissions reduction will help make more efficient advanced diesel engines cost-competitive with gasoline engines because it will reduce the cost and energy consumption of tailpipe emissions treatment.

- *Hybrid electric and plug-in hybrid electric vehicles.* Battery cost is one of the central challenges for hybrid electric and plug-in hybrid electric vehicles. DOE officials told us that their goal is to reduce the cost of a battery pack for a hybrid electric vehicle from approximately $920 today to $500 by 2010. Technological challenges include extending the life of the battery pack to last the life of the car, and improving power electronics in the vehicle. Researchers are using lithium-ion and lithium polymer chemistries in the next generation of batteries, instead of the current nickel metal hydride. Officials told us that plug-in hybrids face infrastructure challenges, such as the capacity of household electric wiring systems to recharge a plug-in, and the capacity of the electricity grid if plug-in hybrids are widely adopted. Battery lifetime and cost are also challenges for plug-in hybrids.

- *Lightweight vehicles.* The cost of lightweight materials is the largest barrier to their widespread adoption. In addition, manufacturing capacity for lightweight materials occurs primarily in the aerospace industry and is not available for producing automotive components for lightweight materials.

Current Federal Involvement

- *Advanced diesel engines.* DOE currently conducts research into combustion technology. For example, federal funds are supporting fundamental research to understand low-temperature combustion technology, and the industry is attempting to establish the operating parameters of an engine that facilitate low-temperature combustion.
- *Hybrid electric and plug-in hybrid electric vehicles.* DOE's FreedomCAR program sponsors research that supports the development of hybrid vehicles, specifically with respect to improving the performance, and reducing the cost, of electric batteries.
- *Lightweight vehicles.* DOE currently funds research and development on lightweight materials.

Hydrogen Fuel Cell Vehicles

A hydrogen fuel cell vehicle is powered by the electricity produced from an electrochemical reaction between hydrogen from a hydrogen-containing fuel and oxygen from the air. A fuel cell power system has many components, the key one being the fuel cell "stack," which is many thin, flat cells layered together. Each cell produces energy and the output of all of the cells is used to power a vehicle. Currently, hydrogen fuel cell vehicles are still under development in the United States, and a number of challenges remain for them to become commercially viable. In the United States, government and industry are working on research and demonstration efforts, to facilitate the development and commercialization of hydrogen fuel cell vehicles.

Key Costs

- Because hydrogen fuel cells are still in an early stage of development, the ultimate cost of hydrogen fuel cells is uncertain, but the goal is to make them competitive with gasoline-powered vehicles.

- A fuel cell stack currently costs about $35,000, and a hydrogen fuel cell vehicle about $100,000.

- An ongoing cost-share effort between the federal government and the industry is working toward price targets of $2 to $3 per gallon of gasoline equivalent for hydrogen at the refueling station.

Potential Displacement of Oil

- Federal experts project that hydrogen fuel cell vehicles could have the potential to displace 0.28 million barrels per day by 2025.

Readiness

- Hydrogen fuel cell vehicle technologies are still in research, development, and demonstration.

- Federal experts project that the technology is not likely to be commercially viable before 2015.

Key Challenges

- Key challenges facing the commercialization of hydrogen fuel cell vehicles include the following: (1) hydrogen storage; (2) cost and durability of the fuel cell; and (3) infrastructure costs for producing, distributing, and delivering hydrogen.

Current Federal Involvement

- The federal government conducts research with industry to improve the feasibility of the technology and reduce the costs.

- The government facilitates information-sharing among industry leaders by analyzing sensitive information on hydrogen fuel cell performance from leading automotive and oil companies.

Appendix V: Comments from the Department of Energy

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

Department of Energy
Washington, DC 20585

February 7, 2007

Mr. Mark Metcalfe
U.S. Government Accountability Office
301 Howard Street
Suite 1200
San Francisco, CA 94105

Dear Mr. Metcalfe:

Attached are the Department of Energy's comments for GAO Draft (Job Code GAO-07-283) entitled ***Crude Oil: Uncertainty About Future Oil Supply Makes It Important To Develop a Strategy for Addressing a Potential Peak in Oil Production.***

If you have any questions, you may direct them to David Morehouse, at 202-586-4853.

Sincerely,

Guy F. Caruso
Administrator
Energy Information Administration

Printed with soy ink on recycled paper

DOE Comments - GAO Draft Report (GAO-07-283)

Crude Oil: Uncertainty About Future Oil Supply Makes It Important To Develop a Strategy for Addressing a Potential Peak in Oil Production

Substantive Comments

The Department of Energy (DOE) believes that the Government Accountability Office (GAO) has done a reasonable job of describing the present wide range of estimates of the time when world oil production might peak, as well as in identifying and generally describing many of the significant uncertainties that underlie these estimates' variance. DOE also believes GAO's recommendation that the Federal Government establish a coordinated strategy to deal with a potential peak in oil production is a reasonable one.

In conjunction with other measures, DOE believes it would be useful if the Federal Government, in partnership with allied consuming countries or at least the members of the International Energy Agency, invested substantially more resources in estimating exactly what oil is likely to be produced and what depletion rates are likely to be over a future period of perhaps 5 to 7 years. While not foolproof, a strategy that combines more complete and higher quality geologic, technological, and oil field performance information with more robust supply and demand modeling offers the best opportunity to reduce uncertainties.

See comment 1.

This report is focused on "a potential peak in oil production." It does not, however, definitively state whether the potential peak being addressed involves only the peaking of conventional crude oil production or instead involves the peaking of conventional plus unconventional crude oil production. While the latter seems to be the case given the discussion of extra-heavy oils, tar sands, and oil shale in the report, this should be clearly stated at the outset.

See comment 2.

There are at least two ways in which the report's use of technical terminology may confuse many readers. First, on page 7 the report defines extra-heavy oil as unconventional oil, and defines heavy oil as conventional oil (albeit implicitly, by omission), but thereafter repeatedly confuses the two. Numerous specific corrections for this problem are suggested in the technical comments below.

See comment 3.

Second, the report interchanges the terms "world demand for petroleum products," "world oil consumption," and "oil demand" as though they were equivalents, which they are not. For example, on page 1 beginning at line 5 this is done within the space of three consecutive sentences. In the first of these, the cited 84 million barrels of petroleum products includes ethanol which is not "oil," but a substitute therefore. The clearest way to refer to consumption of petroleum products <u>and</u> their liquid substitutes is as "liquids consumption." A further explanation could indicate that liquids consumption includes products derived from conventional oils, biofuels, coal-to-liquids, natural gas-to-liquids, refinery volumetric gains, upgraded bitumen, and extra-heavy oils.

See comment 4.

The report would also benefit from a clearer distinction between the related but distinct concepts of demand and consumption. Demand is defined either as the willingness and ability to purchase a commodity or service, or as the quantity of a commodity or service wanted at a specified price and time. Consumption, on the other hand, is the utilization of economic goods in the satisfaction of wants or in the process of production resulting chiefly in their destruction, deterioration, or transformation. It can easily be argued that crude oil is demanded and consumed at the refinery, whereas petroleum products and their substitutes are demanded and consumed downstream from the refinery or plant. For purely physical reasons, the total quantities of crude oil demanded, supplied, and consumed are less than the total quantities of petroleum liquids demanded, supplied, and consumed, and the latter are, for reasons of substitution or augmentation, less than the total quantities of hydrocarbon liquids demanded, supplied, and consumed. Wherever "demand" or "consumption" appears in the text it should be checked to ensure that the correct term (and concept) has been used.

See comment 5.

Enhanced oil recovery (EOR) technologies do not necessarily raise environmental concerns irrespective of whether their objective is the production of heavy oil, extra-heavy oil, or bitumen (from a tar sand deposit.) For example, the environmental community typically prefers use of EOR in existing fields to exploration in frontier areas. To the extent that carbon dioxide injection EOR operations (CO_2 EOR) can be expanded using man-made CO_2, some analyses have shown that more CO_2 can be sequestered in the producing reservoirs than results from use of the produced oil -- a net environmental improvement. Also, if the process heat for a thermal EOR project is derived from nuclear fission rather than combustion of a fossil fuel, there are no greenhouse gas emissions. On page 18, in the top paragraph, DOE recommends deletion of the last 2 sentences. Similarly on page 20, in the top paragraph, DOE recommends deletion of the last sentence.

See comment 6.

GAO's discussion of alternative fuel and transportation technologies is mostly limited to those used to power autonomous vehicles. Other alternatives ranging from vehicles that draw power from guideways to the substitution of remote sensing and telecommuting for the requirement to travel are not mentioned. While there is some information along these lines in the Appendices, a broader list of alternatives must ultimately be considered.

The following are GAO's comments on the Department of Energy's letter dated February 7, 2007.

GAO Comments

1. We agree that we have not defined a peak as either a peak in conventional or total oil—conventional plus nonconventional. In the course of our study, we found that experts conducting the timing of peak oil studies also do not agree on a single peak concept. Different studies by these experts use different estimates for oil remaining and, as a result, implicitly have different concepts of a peak—a conventional versus a total oil peak. We have added language to the report to clarify this point. The lack of agreement on a peak concept mirrors the disagreement about the very definition of conventional oil versus nonconventional oil. The distinction regarding what portion of heavy oil is conventional is debated by experts. For example, USGS would consider the heavy oil produced in California as conventional oil, while IEA would not—the latter considers all heavy (and extra-heavy) oil to be nonconventional. For the purposes of this report, we have adopted IEA's definition of nonconventional oil, which includes all heavy oil.

2. We agree that the use of heavy and extra-heavy oil may be confusing in sections of this report, and we have implemented some of the suggestions that DOE provided in their technical comments.

3. With regard to the inclusion of some ethanol in petroleum consumption as reported on page 1 of the report, we asked EIA staff to identify how much of such nonpetroleum liquids are in the figure. They told us that just under one-third of 1 percent of the world petroleum consumption data they report is comprised of ethanol, and we noted this in a footnote on page 1 of the report. We decided to continue to call it petroleum consumption, rather than "liquids consumption" as suggested by DOE because the former is what EIA calls it and because the nonpetroleum component is so small.

4. We agree that our language regarding the use of oil consumption and oil demand is confusing in some sections of the report. Overall, the report makes the point that, all other things equal, the faster the world consumes oil, the sooner we will use up the oil and reach a peak. The report also makes the point that future demand for oil, which depends on many factors, including world economic growth, will determine just how fast we consume oil. We have made some changes to the text to clarify when we are talking about consumption of oil and when we are talking about the demand for oil.

5. We do not disagree that the environmental costs of EOR are lower than for some of the other technologies examined, and we did not try to rank the environmental costs of all the alternatives we examined. However, we believe that these costs are relevant for assessing the potential impacts of producing more of our oil using such technologies. Therefore, we left that discussion in the report but added language attributing DOE's views on this.

6. We agree with DOE's assessment that there is a broader range of transportation technologies besides those used to power autonomous vehicles. We chose to focus on the technologies that experts currently believe have the most potential for reducing oil consumption in the light-duty vehicle sector, which accounts for 60 percent of the transportation sector's consumption of petroleum-based energy. We encourage DOE and other agencies to consider the full range of oil-displacing technologies as they implement our recommendations to develop a strategy to reduce uncertainty about the timing of a peak in oil production and advise Congress on cost-effective ways to mitigate the consequences of such a peak.

Appendix VI: Comments from the Department of the Interior

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

United States Department of the Interior

OFFICE OF THE ASSISTANT SECRETARY
POLICY, MANAGEMENT AND BUDGET
Washington, D.C. 20240

FEB 14 2007

Mr. James E. Wells Jr.
Director, Natural Resources and Environment
U.S. Government Accountability Office
441 G St., N.W.
Washington, D.C. 20548

Dear Mr. Wells:

Thank you for the opportunity to comment on the draft report GAO 07-28 "Crude Oil, Uncertainty About Future Oil Supply Makes It Important to Develop a Strategy for Addressing a Potential Peak in Oil Production."

Please find enclosed technical comments prepared by Bureaus within the U.S. Department of the Interior. We hope you find these comments useful as you finalize the report.

Sincerely,

R. Thomas Weimer
Assistant Secretary

Enclosure

United States Department of the Interior

U.S. GEOLOGICAL SURVEY
Reston, Virginia 20192

In Reply Refer To:
Mail Stop 105
#2007146-DO

FEB 14 2007

MEMORANDUM

To: Assistant Secretary - Policy, Management and Budget

Through: Mark Limbaugh
Assistant Secretary - Water and Science

From: Mark Myers
Director, U.S. Geological Survey

Subject: Comments on the Government Accountability Office (GAO) draft report entitled, "CRUDE OIL: Uncertainty About Future Oil Supply Makes It Important to Develop a Strategy for Addressing a Potential Peak in Oil Production" (Report Number GAO-07-283).

Thank you for providing the U.S. Geological Survey (USGS) the opportunity to review the U.S. Government Accountability Office (GAO) draft report entitled, "CRUDE OIL: Uncertainty About Future Oil Supply Makes It Important to Develop a Strategy for Addressing a Potential Peak in Oil Production" (Report Number GAO-07-283).

See comment 1.

The report recognizes the importance of increased coordination among agencies, but we express concern over the recommendation the "DOE . . . establish a strategy to coordinate and prioritize federal agency efforts to reduce uncertainty . . . " We would like to emphasize, as the report does, that the U.S. Geological Survey (USGS)/DOI has a major role in global oil resource estimates and a different mission than DOE. The two agencies are complementary and therefore any prioritization of Federal agency efforts should be made jointly, not just by DOE, as the recommendation reads on the cover of the draft report.

See comment 2.

The document fairly portrays the USGS and its role in providing unbiased science for others to make policy, decisions, forecasts, etc. However, there are a few instances in the document where it is implied that the USGS said it could take additional steps to mitigate the consequences of a peak (for example, last paragraph on page 40). This sentence directly follows a list of what the USGS has proposed it could do to improve or expand our global resource estimates, which will reduce the uncertainty surrounding estimates of global oil resources. It needs to be made clear that the USGS cannot take steps to "mitigate the consequences of a peak." That is neither the purview nor responsibility of the USGS. The USGS provides information about undiscovered resources, research into continuous, unconventional, nonconventional resources, etc. to better characterize the global petroleum endowment, in order that others can make policy and perhaps take steps to mitigate the peak.

We hope our comments will assist the GAO in preparing the final report.

The following are GAO's comments on the Department of the Interior's letter dated February 14, 2007.

GAO Comments

1. We agree that DOE and Interior will both play a vital role in implementing our recommendation. We have made the appropriate wording change to the Highlights page of the report to clarify that our recommendation is that DOE work in conjunction with other key agencies to establish a strategy to coordinate and prioritize federal agency efforts to reduce the uncertainty surrounding the timing of a peak and to advise Congress on how best to mitigate consequences.

2. We agree that mitigating the consequences of a peak is outside the purview of Interior. The examples cited highlight the areas where Interior can help reduce the uncertainty surrounding the estimates of global resources. We have changed the wording accordingly to make this distinction clear.

Appendix VII: GAO Contact and Staff Acknowledgments

GAO Contact

Jim Wells, (202) 512-3841

Staff Acknowledgments

In addition to the contact person named above, Mark Gaffigan, Acting Director; Frank Rusco, Assistant Director; Godwin Agbara; Vipin Arora; Virginia Chanley; Mark Metcalfe; Cynthia Norris; Diahanna Post; Rebecca Sandulli; Carol H. Shulman; Barbara Timmerman; and Margit Willems-Whitaker made key contributions to this report.

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