CHAPTER 2

Peaking of World Oil Production and Its Mitigation

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Oil is the lifeblood of modern civilization. It fuels the vast majority of the world's mechanized transportation equipment, including its automobiles, trucks, airplanes, trains, ships, and farm equipment. Oil is also the primary feedstock for many of the chemicals that are essential to modern life.

The Earth's endowment of oil is finite, and demand for oil continues to increase at an significant rate. Accordingly, geologists know that at some future date the conventional oil supply will no longer be capable of satisfying world demand. At that point, world conventional oil production will have peaked and will begin to decline.

Under business-as-usual conditions, world oil demand will continue to grow, increasing approximately 2 percent per year, driven primarily by the transportation sector. The economic and physical lifetimes of existing transportation equipment are measured on decade time scales. Since turnover rates are low, rapid changeover in transportation end-use equipment is inherently time consuming.

Oil peaking represents a liquid fuels problem, not an "energy crisis." Motor vehicles, aircraft, trains, and ships simply have no ready alternative to liquid fuels. Nonhydrocarbon energy sources, such as solar, wind, photovoltaics, nuclear power, geothermal, and fusion technology, produce electricity, not liquid fuels, so their widespread use in transportation is certainly decades away. Accordingly, mitigation of declining world oil production must be narrowly focused.

The world has never faced a problem like the peaking of oil. Previous energy transitions—such as wood to coal or coal to oil—were gradual and evolutionary; oil peaking will be abrupt and revolutionary. Without massive mitigation more than a decade before the fact, the problem will be pervasive and devastating.

The inevitable peaking of world oil production presents the world with an unprecedented risk management problem. The rapid rise in world oil prices from 2004 through 2005 may appear modest in comparison to the price escalations and oil shortages that are almost certain to accompany the peaking of world conventional oil production. As peaking is approached, oil prices and price volatility will increase dramatically, and, without timely mitigation, the economic, social, and political costs will be unprecedented. Viable mitigation options exist on both the supply and demand sides, but to have substantial impact on a world scale, they must be initiated more than a decade in advance of peaking.

Peaking of World Conventional Oil Production

Oil was formed by geological processes hundreds of millions of years ago and is not found everywhere. It is typically found in underground reservoirs of dramatically different sizes, at varying depths, and with widely varying characteristics. The largest oil reservoirs are called "super giants," many of which were discovered in the Middle East. Because of their size and other characteristics, super-giant reservoirs are generally the easiest to find, the most economic to develop, and the longest lived. The last super-giant oil reservoirs discovered worldwide were found in 1967 and 1968. Since then, smaller reservoirs of varying sizes have been discovered in what are called "oil prone" locations worldwide. Many smaller reservoirs must be discovered to replace one of the world's super giants.

Future world oil production must also include the output from all the yet-to-be discovered oil fields in their various states of development. This is an extremely complex summation problem because of the variability and large possible biases in publicly available data. The remarkable complexity of the problem can easily lead to incorrect conclusions, either positive or negative.

Reaching a global oil production peak does not mean that the world is "running out" of oil. Each tapped reservoir reaches a maximum oil production rate, which typically occurs after roughly half of the recoverable oil in the field has been produced. Satisfying increasing oil demand, therefore, not only requires continuing to produce older oil fields with their declining production, it also requires finding new ones, capable of producing sufficient quantities of oil to both compensate for shrinking production from older fields and to provide the increases demanded by the market. As discovery rates fail to replace diminishing production rates from known fields in the face of increased demand, a global oil shortage emerges.

A pattern of declining oil discovery has already emerged. Extensive exploration has occurred worldwide for the last 30 years, but results have been disappointing. If recent trends hold, there is little reason to expect that exploration success will dramatically improve in the future. This situation is evident in Figure 2-1, which shows the difference between annual world

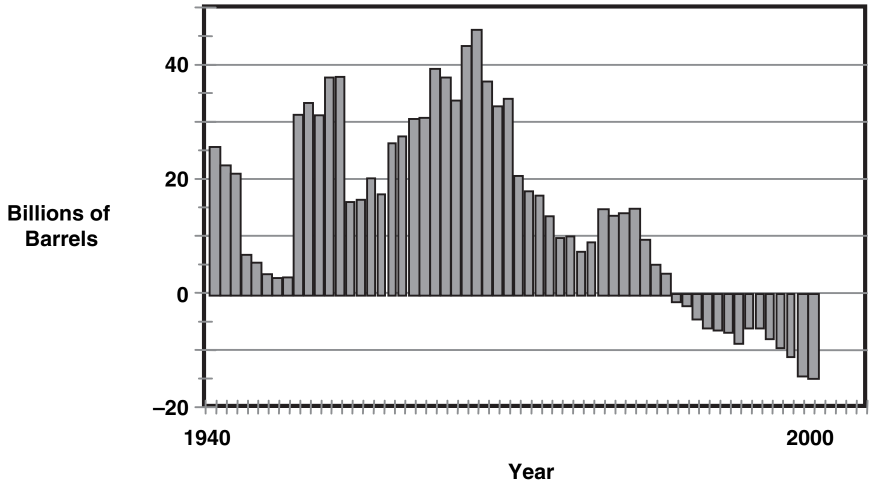

FIGURE 2-1. Difference between annual world oil reserves additions and annual consumption; 1940–2000.

oil reserves additions minus annual consumption (Aleklett and Campbell, 2003). It clearly shows a world moving from a long period in which reserve additions were much greater than consumption into an era where annual additions are falling increasingly short of annual consumption.

Oil Reserves

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

The concept of reserves is often misunderstood. Reserves is an estimate of the amount of oil in an oil field that can be extracted at an assumed cost. Thus, a higher oil price outlook often means that more oil can be produced, but geology places an upper limit on price-dependent reserves growth. In well-managed oil fields, the upper limit is often only 10 to 20 percent more than what is available at lower prices. Reserves and production should not be confused. An oil field can have large estimated reserves, but if the field is past its maximum production, the remaining reserves will still be produced at a declining rate.

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

Projections of the Peaking of World Oil Production

World oil demand is expected to grow more than 40 percent by 2025 (U.S. Department of Energy, 2005). It is questionable whether global pro-duction can expand to meet this increase in demand before production reaches its peak. Recently, many credible analysts have become much more pessimistic about the possibility of finding the huge new reserves needed to meet growing world demand. Even the optimistic forecasts frequently suggest that world oil peaking will occur in less than 25 years. If this occurs, enormous economic disruption, as only glimpsed during the 1973 oil embargo and the 1979 Iranian oil cutoff, is likely to result.

Various individuals and groups have used available information and geological estimates to develop projections for when world oil production might peak. A sampling of recent projections is shown in Table 2-1.

Previous Oil Supply Shortfalls and Disruptions

There have been over a dozen global oil supply disruptions over the past half-century (U.S. Department of Energy 2000). Disruptions ranged in dura-

TABLE 2-1. Projections of the Peaking of World Oil Production

Projected Date	*Source of Projection*	*Background & Reference*
2006–2007	Bakhitari, A. M. S.	Oil executive (Iran) (Bakhitari, 2004)
2007–2009	Simmons, M. R.	Investment banker (U.S.) (Simmons, 2003)
After 2007	Skrebowski, C.	Petroleum journal editor (U.K.) (Skrebowski, 2004)
Before 2009	Deffeyes, K. S.	Oil company geologist (ret., U.S.) (Deffeyes, 2003)
Before 2010	Goodstein, D.	Vice Provost, Cal Tech (U.S.) (Goodstein, 2004)
Around 2010	Campbell, C. J.	Oil company geologist (ret., Ireland) (Campbell, 2003)
After 2010	World Energy Council	World Non-Government Org. (World Energy Council, 2003)
2012	Pang Xiongqi	Petroleum engineer (China) (Xiongqi, 2005)
2010–2020	Laherrere, J.	Oil geologist (ret., France) (Laherrere, 2003)
2016	EIA nominal case	DOE analysis/information (U.S.) (U.S. Department of Energy, 2000)
After 2020	CERA	Energy consultants (U.S.) (Jackson et al., 2004)
2025 or later	Shell	Major oil company (U.K.) (Davis, 2003)

tion from 1 to 44 months. Percentage supply shortfalls varied from roughly 1 percent to nearly 14 percent of world production. The most traumatic disruption, in 1973–1974, was not the most severe, but it nevertheless led to greatly increased oil prices and caused significant worldwide economic damage. A second major disruption, in 1979, was also neither the longest nor the most severe, although it, too, led to significant global economic problems. The 1973 and the 1979 disruptions are frequently assumed to be the most relevant in predicting what might happen at world oil peaking.

Higher oil prices during these disruptions resulted in increased costs for the production and delivery of goods and services. High prices boosted inflation and unemployment, reduced demand for products other than oil, lowered capital investment, and undercut consumer and business confidence. Tax revenues declined and budget deficits increased, driving up interest rates. These effects were magnified during periods when oil price increases were the most abrupt and severe. Government policies could not eliminate the adverse impacts of sudden, severe oil disruptions. Some policies reduced the damage, while contradictory monetary and fiscal policies to control inflation exacerbated recessionary income and unemployment effects.

Estimates of the damage caused by past oil price disruptions vary substantially, but without a doubt, the effects were significant. Economic growth decreased in most oil importing countries following the disruptions of 1973–1974 and 1979. The impact of the first oil shock was accentuated by inappropriate policy responses (Lee and Ratti, 1995; Hamilton and Herrera, 2003). Despite a decline in the ratio of oil consumption to the gross domestic product (GDP) in many developed countries over the past three decades, oil remains vital, and there is considerable empirical evidence regarding the effects of oil price shocks:

- The loss suffered by the countries belonging to the Organization of Economic Cooperation and Development (OECD) in the recession from 1974 to 1975 that immediately followed the first oil disruption amounted to $350 billion in 1974 dollars, or $1.1 trillion in 2003 dollars, although part of this loss was related to factors other than oil (Bird, 2003).
- The loss resulting from the 1979 oil disruption was about 3 percent of GDP, or $350 billion (1980 dollars) in 1980, rising to 4.25 percent or $570 billion in 1981, and accounted for much of the decline in economic growth and the increase in inflation and unemployment in the OECD in the recession of 1981 and 1982. These losses totaled about $700 billion and $1.1 trillion, respectively, in 2003 dollars.
- The effect of the oil price upsurge in 1990–1991 was more modest because price increases were smaller, they did not persist, and oil intensity in OECD countries had declined, thereby decreasing their economic vulnerability to oil price jumps.

- Although oil intensity and the share of oil in total imports have declined in recent years, OECD economies remain vulnerable to higher oil prices because of the "life blood" nature of liquid fuel use.

The impact of sustained, significantly increased oil prices associated with oil peaking will be severe. Virtually certain are increases in inflation and unemployment, declines in the output of goods and services, and a decline in living standards. Without timely mitigation, the impact on the developed economies will almost certainly be extremely damaging, while many developing nations will likely be much worse off.

Mitigation Options and Issues

Fortunately, a number of options exist that can be applied to lessen oil dependence and reduce economic vulnerability to oil price increases. They include reduction in energy demand, methods to increase oil production, and the introduction of alternative fuels that can substitute for oil in key market applications.

Energy Conservation

Practical mitigation of the problems associated with world oil peaking must include fuel efficiency technologies that could have an impact on a large scale over time. It is clear that automobiles and light trucks, together termed light-duty vehicles (LDVs), represent the largest targets for consumption reduction worldwide.

Government-mandated vehicle fuel efficiency requirements are certain to be an element in the mitigation of world oil peaking. In addition to major fuel efficiency improvements in conventional vehicles, one result would almost certainly be the more rapid deployment of hybrid electric vehicles. Market penetration of these technologies cannot happen rapidly because of the time and effort required for manufacturers to retool their factories for large-scale production and because of the slow turnover of existing stock. In addition, a shift from gasoline to diesel fuel would require a major refitting of refineries, which would take time.

It is difficult to project what the fuel economy benefits of hybrid electric or diesel powered LDVs might be on an international scale because consumer preferences will likely change once the public understands the potential impacts of the peaking of world oil production. The fuel efficiency benefits that hybrid electric drivetrains might provide for heavy-duty trucks and buses are likely smaller than for LDVs for a number of reasons, including the fact that there has long been a commercial demand for higher-efficiency technologies in order to minimize fuel costs in these professional fleets.

Hybrid electric technology can also impact the medium duty truck fleet, which is now heavily populated with diesel engines. For example, road testing of diesel hybrid electric drivetrains in FedEx trucks began recently, with fuel economy benefits claimed to be 33 percent (Eaton Corporation, 2004). On the other hand, there appear to be limits to the fuel economy benefits of hybrid drivetrains in large vehicles; for example, the fuel savings in hybrid buses might only be in the 10 percent range (National Renewable Energy Laboratory, 2002).

Improved Oil Recovery

Improved oil recovery (IOR) is used to varying degrees in all oil fields. A particularly notable opportunity to increase production from existing oil fields is to use enhanced oil recovery technology (EOR), also known as tertiary recovery. EOR is usually initiated after primary and secondary recovery techniques have maximized their productivity. Primary production is the process by which oil naturally flows to the surface because oil is under pressure underground. Secondary recovery involves the injection of water into a reservoir to force additional oil to the surface.

EOR has been practiced since the 1950s in various conventional oil fields, primarily in the United States. The process that likely has the largest worldwide potential is miscible flooding wherein CO2 or light hydrocarbons are injected into oil reservoirs, where they act as solvents to move residual oil.

Heavy Oil and Oil Sands

This category of unconventional oil includes a variety of viscous oils that are called heavy oil, bitumen, oil sands, and tar sands. These oils have the potential to play a much larger role in satisfying the world's needs for liquid fuels in the future.

The largest deposits of unconventional oils exist in Canada and Venezuela, with smaller resources in Russia, Europe, and the United States. While the sizes of the Canadian and Venezuela resources are enormous, 3 to 4 trillion barrels in total, the amount of oil estimated to be economically recoverable is of the order of 600 billion barrels. This relatively low fraction is in large part due to the extreme difficulty in extracting these oils (Williams, 2003). While recovery may increase with higher world oil prices, estimation of the increased reserves would be highly speculation.

Here are some of the reasons why the production of unconventional oils has not been more extensive:

- Production costs for unconventional oils are typically much higher than for conventional oil.
- Significant quantities of energy are required to recover and transport unconventional oils.
- Unconventional oils are of lower quality and, therefore, are more expensive to refine into clean transportation fuels than conventional oils.

- There can be significant environmental problems associated with the production of these unconventional oils.

Gas-to-Liquids (GTL)

Very large reservoirs of natural gas exist around the world, many in locations that are isolated from natural gas–consuming markets. Significant quantities of this "stranded gas" are being liquefied and transported to markets in refrigerated, pressurized ships in the form of liquefied natural gas (LNG). Another method of bringing stranded natural gas to world markets is to disassociate the methane molecules, add steam, and convert the resultant mixture to high-quality liquid fuels via the Fisher-Tropsch (F-T) process. F-T based GTL results in clean, finished fuels, ready for use in existing end-use equipment with only modest finishing and blending. GTL processes have undergone significant development over the past decade.

Coal Liquefaction

To derive liquid fuels from coal, the leading process involves gasification of the coal, removal of impurities from the resultant gas, and then synthesis of liquid fuels, using the F-T process. Gas cleanup technologies are well developed and deployed in refineries worldwide. F-T synthesis is also well developed and commercially practiced. A number of coal liquefaction plants were built and operated during World War II, and the Sasol Company in South Africa subsequently built several larger and more modern facilities (Kruger, 1983). Modern gasification technologies have been dramatically improved over the years, with the result that over 200 gasifiers are in commercial operation around the world, most using petroleum coke or coal as their feedstock. Coal liquids from gasification followed by F-T synthesis are of such high quality that they do not need to be refined. Coal liquefaction is believed capable of providing clean substitute fuels at between $35 and $45 per barrel (Gray et al., 2001; Gray, 2005).

Biomass

Biomass can be grown, collected, and converted to substitute liquid fuels by a number of processes. Currently, biomass-to-ethanol is produced on a large scale to provide a gasoline additive in the United States and Brazil, among other places. The market for ethanol derived from biomass is influenced by government requirements and facilitated by generous tax subsidies. Research holds promise of more economical ethanol production from cellulosic, or woody, biomass, but related processes are far from economic. Reducing the cost of growing, harvesting, and converting biomass crops will be necessary (Smith et al., 2004).

Hydrogen

Hydrogen has potential as an alternative to petroleum-based liquid fuels over the long term in some transportation applications. Like electricity, hydrogen is an energy carrier, not a primary fuel; hydrogen production requires an energy source for its production. Energy sources for hydrogen production include natural gas, coal, nuclear power, and renewable resources.

Recently, the U.S. National Research Council (NRC), the operating arm of the U.S. National Academies, completed a study that included an evaluation of the technical, economic, and societal challenges associated with the development of a hydrogen economy (National Research Council, 2004). The NRC concluded that fuel cells must improve by a factor of 10 to 20 in cost, a factor of 5 in lifetime, and roughly a factor of 2 in efficiency in order to become commercial. The NRC did not believe that such improvements could be achieved by technology development alone. It called for new concepts and technical breakthroughs. In other words, today's technologies do not appear practically viable, and the advent of commercial hydrogen vehicles cannot be predicted.

Three Mitigation Scenarios

Issues related to the peaking of world oil production are extremely complex, involve literally trillions of dollars, and are very time sensitive. To explore these matters, three mitigation scenarios with differing starting times (Hirsch, Bezdek, and Wendling, 2005):

- Scenario I: Action is not initiated until oil peaking occurs.
- Scenario II: Action is initiated 10 years before peaking.
- Scenario III: Action is initiated 20 years before peaking.

The analysis was simplified, and the estimates were approximate. Nevertheless, the mitigation envelope that resulted is believed to be indicative of the realities of such an enormous undertaking. The focus was on large-scale, physical mitigation, mainly energy efficiency improvements and the introduction of new fuels, as opposed to analysis of policy actions, such as tax credits, rationing, and automobile speed restrictions. Physical mitigation included implementation of technologies that can substantially reduce the consumption of liquid fuels or increase production, while still delivering comparable services.

The pace that governments and industry choose to mitigate the impacts of the peaking of world oil production is yet to be determined. As a limiting case, the analysis assumed the implementation of crash programs mandated by governments worldwide can be implemented very quickly.

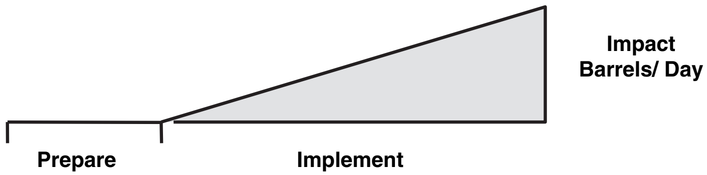

FIGURE 2-2. The delayed wedge approximation for illustrating the impact of the introduction of an energy saving or liquid fuel production technology.

This is obviously the most optimistic situation because government and corporate decision-making is rarely instantaneous.

The model chosen to illustrate the possible effects of likely mitigation actions involves the use of "delayed wedges" to approximate the scale and pace of each action, shown in Figure 2-2. Delayed wedgegraphs are composed of two parts. The first is the preparation time needed prior to tangible market impacts. In the case of efficient transportation, this time is required to redesign vehicles and retool factories to produce more efficient vehicles. In the case of the production of substitute fuels, the delay is associated with planning and construction of relevant facilities.

After the preparation phase, delayed wedges then approximate the penetration of mitigation effects into the marketplace. This might be the growing sales of more fuel-efficient vehicles or the growing production of substitute fuels. The wedges were assumed to continue to expand for a few decades, which simplifies the analysis, but is increasingly less realistic over time because markets will adjust and impact rates will change.

The criteria for selecting candidates for energy efficiency improvements and substitute oil production were as follows:

- The option must produce liquid fuels that can, as produced or as refined, substitute for liquid fuels currently in widespread use—for example, gasoline, diesel, and jet fuel. The end products will thus be compatible with existing distribution systems and end-use equipment.
- The option must be capable of reducing demand for liquid fuels or being implemented on a massive scale, ultimately millions to tens of millions of barrels per day worldwide.
- The option must include technology that is commercial or near commercial, which requires that the process has at least been demonstrated on a commercial scale.
- Substitute fuel production technologies must be inherently energy efficient, assumed to mean that greater than 50 percent of process energy input is contained in the clean liquid fuels product.

- Energy sources or energy efficiency technologies that produce or save electricity were not considered in this context because the focus was on liquid fuels.

Candidates Selected and Rejected

In the end-use efficiency category, a dramatic increase in the efficiency of petroleum-based fuel equipment is one attractive option. The imposition of Corporate Average Fuel Economy (CAFE) requirements for U.S. automobiles in 1975 was one of the most effective of the mandates initiated in response to the oil embargo of 1973 and 1974. In recent years, fuel economy for automobiles has not been a high national priority in the United States.

Nevertheless, fuel efficient hybrid electric drivetrain technology has been penetrating the automobile and truck markets in the United States and elsewhere since the late 1990s. In a period of national oil emergency, hybrid electric and other vehicle fuel efficiency technologies could be massively implemented in new vehicles. A variety of currently available technologies offer fuel economy improvements of 40 percent or more for automobiles and for light and medium trucks.

The fuel production options selected in this analysis were heavy oil and tar sands, coal liquefaction, improved oil recovery, and GTL systems. The rationale was as follows:

- Improved oil recovery is being applied worldwide.
- Oil sands production is currently commercial in Canada and heavy oil is produced in Venezuela and elsewhere.
- Coal liquefaction is a near-commercial technology.
- GTL is a viable commercial technology, which is economic where natural gas is remote from markets.

A number of options were excluded for different reasons. Shale oil represents a huge resource, particularly in the United States. However, practical recovery technologies are still in the development stage and are not yet ready for commercial deployment. Biomass options capable of producing liquid fuels were also not included due to high costs. Ethanol from biomass is currently produced in the United States and Brazilian transportation markets. It is mandated and subsidized in the U.S., but it is not yet economically viable without government support. Biodiesel fuel is a subject of considerable current interest but it, too, is not yet commercially viable. A major research and development effort might change the biomass outlook, if initiated in the near future.

Over 45 percent of world oil consumption is for nontransportation uses. Fuel switching away from some nontransportation uses of liquid fuels is already taking place worldwide. For significant world-scale impact, large substitute energy facilities would have to be constructed to provide the substitute energy. Building these plants would require decades.

Nuclear power, wind, and photovoltaics produce electric power, which is not a near-term substitute fuel in transportation equipment that requires liquid fuels. Many decades after oil peaking, it is conceivable that a massive shift from liquid fuels to electricity might occur in some applications. However, consideration of such changes is speculative at this time.

Modeling World Oil Supply and Demand

It is not possible to predict with certainty when a global peak in conventional oil production will occur or how rapidly production will decline after the peak. Therefore, this analysis did not stipulate a date for peaking. Rather, peaking was assumed at year zero, and the analysis considered effects 20 years before to 20 years after peaking. A shape for world oil peaking was also required, and the production pattern for the U.S. lower 48 states was used as a model of what can occur in a large, complex oil province over the course of over five decades. As shown in Figure 2-3, U.S. lower 48 states production pattern is reasonably approximated by a simple triangular pattern with a roughly 2 percent annual rise before peaking, followed by a 2 percent annual decline after.

For this analysis, world production at peaking was assumed to be 100 million barrels per day (MMbpd), which is 16MMbpd above the current 84 MMbpd world production. The selection of 100MMbpd is not intended as a prediction of magnitude or timing; its use is for illustrative purposes only. Since the wedge estimates are rough estimates, a 100MMbpd peak represents a credible assumption for this kind of analysis. If global peaking were to occur in the next year or two, 100MMbpd might be high by 10 to

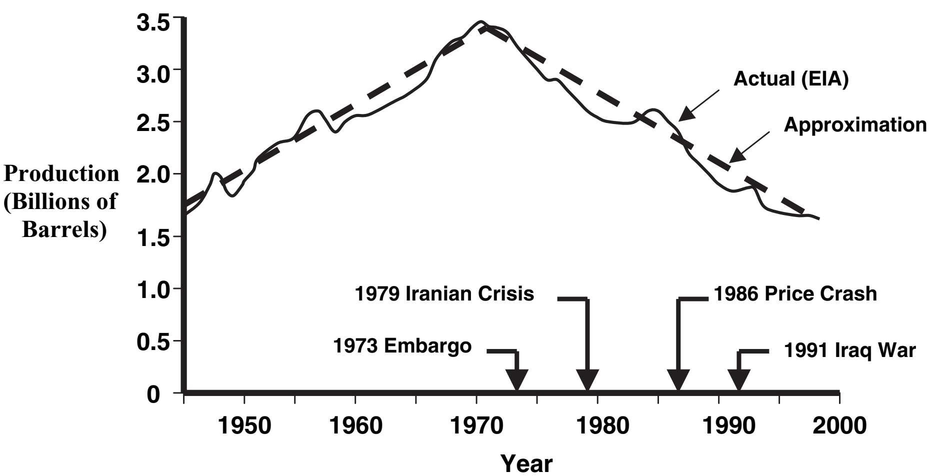

FIGURE 2-3. U.S. lower 48 oil production, 1945–2000.

15 percent. If peaking occurs at 125MMbpd at some future date, the 100MMbpd assumption would be low by 25 percent.

Another important variable is future world oil demand growth. The World Energy Council has made the following prediction: "Oil demand is projected to increase at about 1.9 percent per year, rising from an actual level of about 75.7MMbpd in 2000 to between 113 and 115MMbpd in 2020, an increase of between 37.5 and 39.5MMbpd" (World Energy Council, 2001). Recent trends indicate a world oil annual demand growth in excess of 3 percent, driven in part by rapidly increasing oil consumption in China and India. However, sustaining such a high growth rate on a continuing basis seems unlikely. With these considerations in mind, a 2 percent growth in demand after peaking was assumed. This extrapolation of demand after peaking provides a reference that facilitates calculation of supply shortfalls. The assumption has the benefit of simplicity, but it ignores the real-world feedback of oil price escalation on demand, which is sure to happen but will be extremely difficult to forecast.

Some other analysts have projected world oil production decline rates of 3 to 8 percent, well above the 2 percent assumed in this analysis. Such higher decline rates would make the mitigation problem much more difficult (Al-Husseini, 2004).

Results of Crash Program Mitigation

The estimated contributions over 15 years of a worldwide crash program to expand production of the energy resources, including efficiency, selected as viable options in this analysis are shown in Figure 2-4. The results of the analyses of future oil supply, demand, and supply shortfall, including the

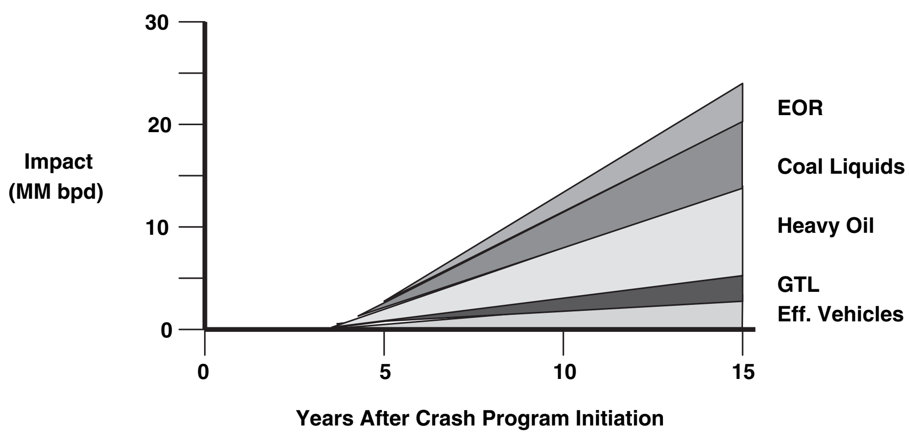

FIGURE 2-4. Estimated contributions of the worldwide crash program implementation of various oil-peaking mitigation options.

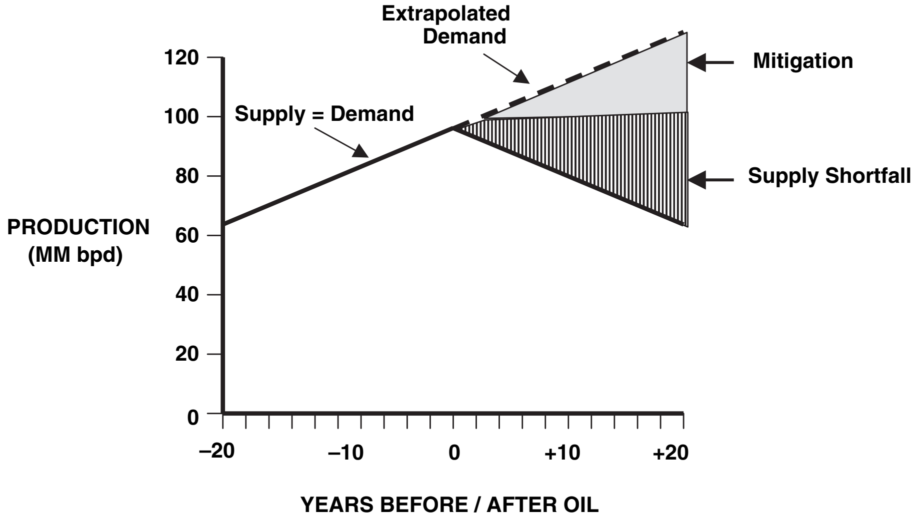

FIGURE 2-5. Mitigation crash programs started at the time of world oil peaking: A significant supply shortfall occurs over the forecast period.

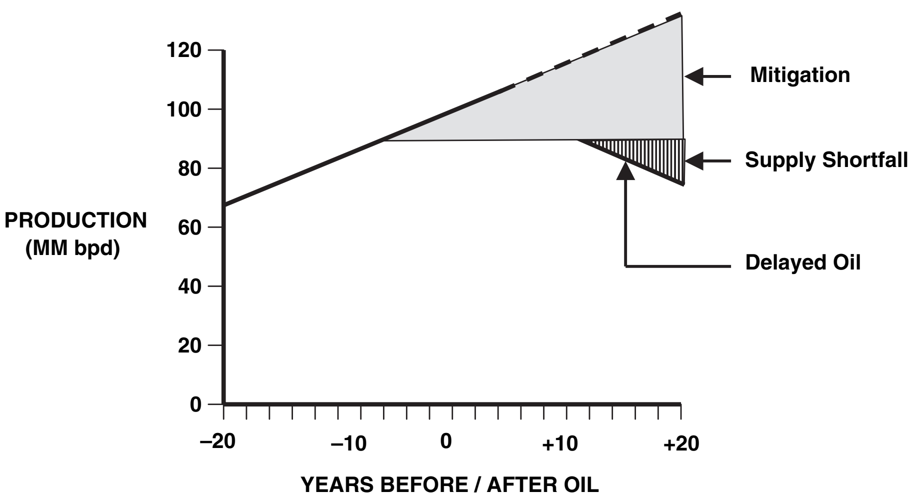

FIGURE 2-6. Mitigation crash programs started 10 years before world oil peaking: A moderate supply shortfall occurs after roughly 10 years.

impact of mitigation options on the assumed world oil peaking pattern, appear in Figures 2-5, 2-6, and 2-7. The major findings are as follows:

- Waiting until world oil production peaks before taking crash program action (Figure 2-5) leaves the world with a significant liquid fuel deficit for more than two decades.

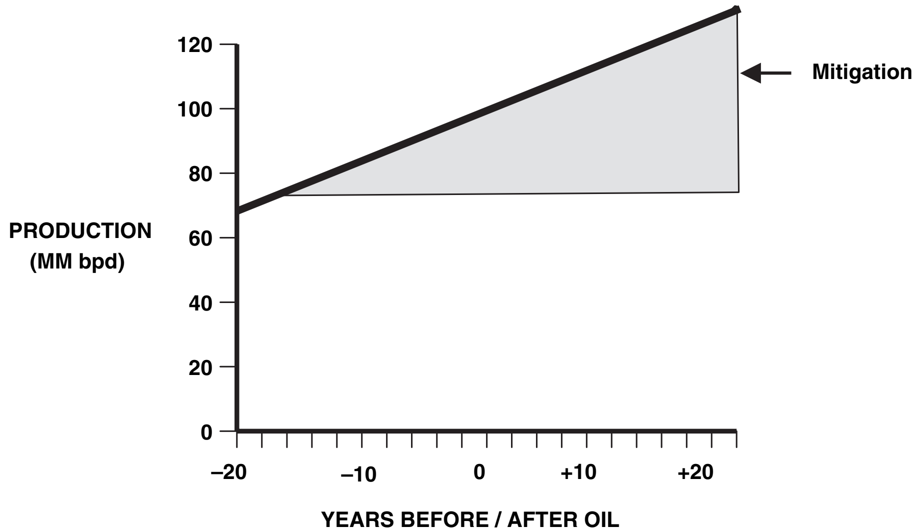

FIGURE 2-7. Mitigation crash programs started 20 years before world oil peaking: No supply shortfall occurs during the forecast period.

- Initiating a mitigation crash program 10 years before world oil peaking (Figure 2-6) helps considerably but still leaves a liquid fuels shortfall roughly a decade after the time that oil would have peaked.
- Initiating a mitigation crash program 20 years before peaking (Figure 2-7) appears to offer the possibility of avoiding a world liquid fuels shortfall for the forecast period.

The obvious conclusion from this analysis is that with adequate, timely mitigation, the worldwide economic costs of oil peaking can be minimized. If mitigation were to be too little or too late, a balance between oil supply and healthy world economic growth can only be achieved after a period of massive shortages, which would translate to significant economic hardship worldwide.

Risk Management

It is possible that peaking may not occur for several decades, but it is also possible that peaking may occur in the very near future. The world is thus faced with a daunting risk management problem. On the one hand, mitigation initiated too early would be premature if peaking is still several decades away. On the other hand, if peaking is imminent, failure to initiate mitigation quickly will have significant economic and social costs to the United States and the world.

The two risks are asymmetric. Mitigation actions initiated prematurely will be costly and could result in a suboptimal use of resources. Late initiation of mitigation may result in dire economic consequences. The world has never confronted a problem like this, and the failure to act on a timely basis is almost certain to have debilitating impacts. Risk minimization requires the implementation of mitigation measures well prior to peaking. Since it is uncertain when peaking will occur, the challenge is indeed significant.

Wildcards in Oil Peak Predictions

There are a number of factors that could conceivably impact the peaking of world oil production. Among the upsides, or factors that might ease the problems of world oil peaking, is the possibility that the pessimists are wrong again and peaking does not occur for many decades. Alternatively, Middle East oil reserves turn out to be much larger than publicly stated or a number of new super-giant oil fields are found and brought into production well before oil peaking might otherwise have occurred. Here are some other possible upsides:

- High world oil prices over a decade or more induce a higher level of energy conservation and efficiency.
- The United States and other nations decide to institute significantly more stringent fuel efficiency standards well before world oil peaking.
- World economic and population growth slows, and future demand is much less than anticipated.
- China and India decide to initiate or strengthen various fuel efficiency programs and other energy efficiency requirements, reducing the rate of growth of their oil requirements.
- Oil prices stay at a high enough level on a sustained basis so that industry begins construction of substitute fuels plants well before oil peaking.
- Huge new reserves of natural gas are discovered, a portion of which is converted to liquid fuels.
- Some kind of scientific breakthrough comes into commercial use, mitigating oil demand well before oil production peaks.

On the other hand, there are also several factors that might exacerbate the problem presented by a peaking of world oil. First of all, the advent of peak oil could come earlier than projected even by the most pessimistic forecasts. This could result if Middle East reserves turn out to be much less than stated or if extreme terrorism inflicts major damage to oil production, transportation, refining, and/or distribution facilities. Other concerns are that political instability in major oil producing countries, especially those in the volatile Middle East, results in unexpected, sustained world-scale oil shortages. The following are other possible downsides:

- Market signals mask the onset of peaking, delaying the initiation of mitigation.

- Consumers continue to demand larger, less-fuel-efficient vehicles.
- Expansion of energy production is hindered by increasing environmental, administrative, and institutional challenges, creating shortages beyond just liquid fuels.

Conclusion

Over the past century the development of economies and lifestyles has been fundamentally shaped by the availability of abundant, low-cost oil. A number of competent forecasters now project peaking within a decade; others contend it will occur later. Prediction of peaking is extremely difficult because of geological complexities, measurement problems, pricing variations, demand elasticity, and political distortions. Peaking will happen, but the timing is uncertain.

The analysis of the impact of mitigation strategies on future oil supplies performed in this study leads to several conclusions. First, oil scarcity and severalfold oil price increases due to world oil production peaking will almost certainly have dramatic negative economic impacts. The decade after the onset of world oil peaking may resemble the period after the 1973 to 1974 oil embargo but last for a decade or more. World economic losses could be measured on a $10 trillion scale.

Mitigation strategies will require an intense effort to implement over decades. This inescapable conclusion is based on the time required to replace vast numbers of liquid fuel–consuming vehicles and the time required to build a substantial number of substitute fuel production facilities. Scenario analysis suggests that waiting until world oil production peaks before taking crash program action would leave the world with a significant liquid fuel deficit for more than two decades. Initiating a crash mitigation program 10 years before world oil peaking helps considerably but still leaves a liquid fuels shortfall roughly a decade after the time that oil would have peaked.

Only by initiating a mitigation crash program 20 years before peaking might the world avoid a significant world liquid fuels shortfall. The conclusion is that the global disruption from oil peaking can be minimized through adequate, timely mitigation. If mitigation is too little or too late, however, a global balance of oil supply and healthy economic demand will be achieved only after a prolonged period of massive shortages and economic hardships.

Sustained high oil prices in the future are likely to stimulate some level of forced demand reduction. Stricter end-use efficiency requirements can further reduce embedded demand, but substantial, world-scale change will require more than a decade. Production of large amounts of substitute liquid fuels can and must be provided. A number of commercial or near-commercial substitute fuel production technologies are currently available, so the production of large amounts of substitute liquid fuels is technically and economically feasible, albeit time-consuming and expensive.

The peaking of world conventional oil production presents a classic risk management problem. Mitigation efforts initiated earlier than required may turn out to be premature, if peaking is long delayed. On the other hand, if peaking is imminent, failure to initiate timely mitigation could be extremely damaging. Prudent risk management requires the planning and implementation of mitigation well before peaking. Early mitigation will almost certainly be less expensive and less damaging to the world's economies than delayed mitigation.

Intervention by governments will be required in order to implement early mitigation strategies. The experiences of the 1970s and 1980s offer important lessons and guidance as to government actions that might be more or less desirable. But the process will not be easy. Expediency may require major changes to existing administrative and regulatory procedures for new facility development, such as lengthy environmental reviews and extensive public involvement.

Without mitigation, however, the peaking of world oil production will almost certainly cause major worldwide economic upheaval. Given enough lead time, the problems are solvable with existing technologies. New technologies are certain to help but on a longer time scale. Appropriately executed risk management could dramatically minimize the damages that might otherwise occur.

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