Perspective

Peaking of World Oil Production and Its Mitigation

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Introduction

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

The demand for oil continues to increase with time, and at some time, conventional oil supply will no longer be capable of satisfying world demand. At that point world conventional oil production will have peaked.

The peaking of world oil production presents the world with an unprecedented risk management problem. As peaking is approached, without timely mitigation liquid fuel prices and price volatility will increase dramatically, and the economic, social, and political costs will be unprecedented. Indeed, the rapid rise in world oil prices in the 2004-5 period may likely appear modest in comparison to the price escalations and oil shortages that are almost certain to accompany the peaking of world conventional oil production. The peaking of world oil production could create enormous economic disruption, as only glimpsed during the 1973 oil embargo and the 1979 Iranian oil cut-off.

There are a significant and growing number of peaking studies and forecasts in the open literature. However, since much of the relevant oil reserves data is shrouded in secrecy, oil peaking forecasting is far from being definitive. Against this background, we focus on mitigation of oil peaking without selecting a date for that occurrence. We consider three scenarios in order to estimate the time required for implementation of effective worldwide mitigation strategies. Viable mitigation options exist on both the supply and demand sides, but to have substantial impact on a world scale, but we argue that they must be initiated more than a decade in advance of peaking[†].

Peaking of World Conventional Oil Production

Oil 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 were found in 1967 and 1968. Since then, smaller reservoirs of varying sizes have been discovered in what are called "oil prone" locations worldwide — oil is not found everywhere.

Geologists understand that oil is a finite resource in the earth's crust, and at some future date, world oil production will reach a peak, after which production will decline. This logic follows from the well-established behavior that the output of individual oil fields rises after discovery, reaches a peak and declines thereafter. It is important to recognize that oil production peaking is not the same as "running out." Peaking is an oil field's maximum oil production rate, which typically occurs after roughly half of the recoverable oil in the field has been produced. In many ways, what is likely to happen on a world scale is similar to what happens to individual oil fields, because world production is the sum total of production from thousands of oil fields.

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[†]This article is based on the research reported in Ref. 1.

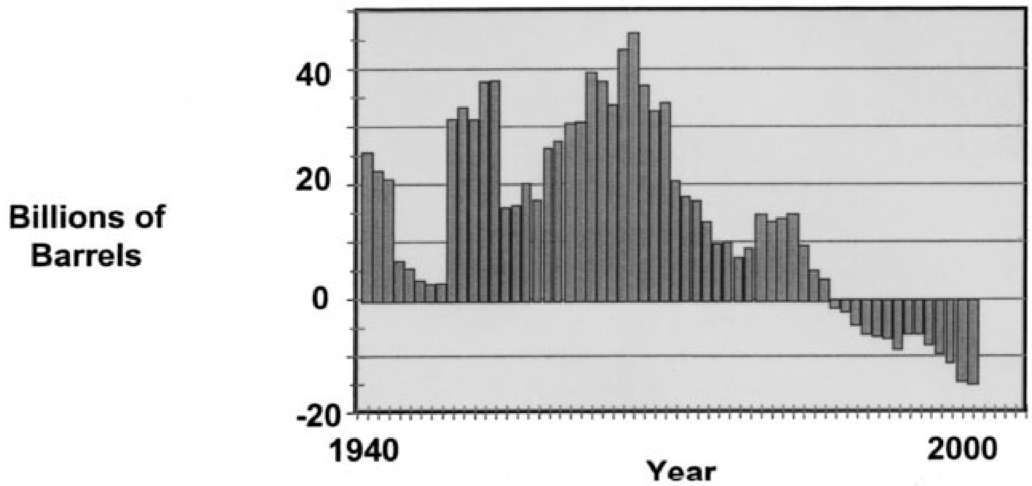

Figure 1. Difference between annual world oil reserves additions and annual consumption—1940–2000.

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. The total recoverable oil in a reservoir is its so-called "reserves."

Oil Reserves

The concept of reserves is generally not well understood. "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, it is often 10 – 20% more than what is available at lower prices.

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

Reserves and production should not be confused. An oil field can have large estimated reserves, but if the field is past its maximum production, the remaining reserves can only be produced at a declining rate.

Production Peaking

World oil demand is expected to grow more than 40% by 2025.[2] Since oil production from individual oil fields grows to a peak and then declines, new oil fields must be continually discovered and brought into production to compensate for the depletion of older ones and to provide the increases demanded by the market. When world oil production peaks, there will still be large reserves remaining. Peaking means that the rate of world oil production cannot increase, and that production will thereafter decrease with time.

Past predictions typically forecast peaking in the succeeding 10 – 20 year period. Most such predictions were wrong. 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 many of the optimistic forecasts suggest that world oil peaking will occur in less than 25 years.

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 1, which shows the difference between annual world oil reserves additions minus annual consumption.[3] The image is one of a world moving from a long period in which reserve additions were much greater than consumption, to an era in which annual additions are falling increasingly below annual consumption.

Projections of the Peaking of World oil Production

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 1.

Previous Oil Supply Shortfalls, Disruptions, and Effects

There have been over a dozen global oil supply disruptions[4-8] over the past half-century. Briefly:

- Disruptions ranged in duration from one to 44 months. Percentage supply shortfalls varied from roughly one percent to nearly 14% of world production.
- The most traumatic disruption, 1973-74, was not the most severe, but it nevertheless lead to greatly increased oil prices and significant worldwide economic damage.
- The second most traumatic disruption, 1979, was also neither the longest or the most severe.

The 1973-74 and 1979 disruptions are the most relevant to what might happen at world oil peaking, but both were relatively short-lived because additional production capacity was available in OPEC. That will not be the case with world oil peaking, and higher oil prices will result.

Table 1. Projections of the Peaking of World Oil Production

Projected Date	Source of Projection	Background
2006–2007	Bakhitari, A. M. S. (18)	Oil Executive (Iran)
2007–2009	Simmons, M. R. (19)	Investment banker (U.S.)
After 2007	Skrebowski, C. (20)	Petroleum journal editor (U.K.)
Before 2009	Deffeyes, K. S. (21)	Oil company geologist (ret., U.S.)
Before 2010	Goodstein, D. (22)	Vice Provost, Cal Tech (U.S.)
Around 2010	Campbell, C. J. (23)	Oil company geologist (ret., Ireland)
After 2010	World Energy Council (24)	World Non-Government Org.
2012	Pang Xiongqi (25)	Petroleum Engineer (China)
2010–2020	Laherrere, J. (26)	Oil geologist (ret., France)
2016	EIA nominal case (27)	U.S. DOE
After 2020	CERA (28)	Energy consultants (U.S.)
2025 or later	Shell (29)	Major oil company (U.K.)

Higher oil prices result in increased costs for the production and delivery of goods and services. High prices can also impact inflation and unemployment, reduce demand for products other than oil, and reduce the capital available for investment. Tax revenues can decline and budget deficits increase, driving up interest rates. These effects will be greater the more abrupt and severe an oil price increase, and will be exacerbated by the impact on consumer and business confidence. Without timely mitigation, the long-run 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

Conservation

Practical mitigation of the problems associated with world oil peaking must include fuel efficiency technologies that will have a large scale impact over time. It is clear that automobiles and light trucks (light duty vehicles or 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 diesel and hybrid power trains. 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 vehicles. In addition, a shift from gasoline to diesel fuel would require a major refitting of refineries, which will take time.

It is difficult to project what the fuel economy benefits of hybrid or diesel 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 hybrids might provide for heavy-duty trucks and buses are likely less 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 for these fleets.

Improved oil recovery

Improved oil recovery (IOR) is used to varying degrees in almost all oil fields worldwide. An important opportunity to increase production from existing oil fields is the use of enhanced oil recovery technology (EOR), also known as tertiary recovery. EOR is usually initiated after primary and secondary recovery have provided most of what they can provide. 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 of America. The process that likely has the largest worldwide potential is miscible flooding, wherein carbon dioxide (CO_2), nitrogen or light hydrocarbons are injected into oil reservoirs, where they act as solvents and/or pressures to move residual oil. Of the three options, CO_2 flooding has proven to be the most frequently useful.

Heavy oil and oil sands

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

The largest deposits of these oils exist in Canada and Venezuela, with smaller resources in Russia, Europe and the U.S. While the size of the Canadian and Venezuela resources are enormous, 3-4 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 extremely difficult task of extracting these oils[§].[9]

The reasons why the production of unconventional oils has not been more extensive is as follows: (1) Production costs for unconventional oils are typically much higher than for conven-

[‡]Economists contend that this amount will increase with higher world oil prices, which is almost certainly correct. However, without careful analysis, estimation of the increased reserves would be strictly speculation.

[§]These numbers are subject to revision upward or downward depending on future geological findings, advancing technology, or higher oil prices.

tional oil; (2) significant quantities of energy are required to recover and transport unconventional oils; (3) unconventional oils are of lower quality and, therefore, are more expensive to refine into clean transportation fuels than conventional oils, and (4) there are severe environmental problems associated with the production of these unconventional oils, including increased production of greenhouse gases.

Gas-To-Liquids (GTL)

Very large reservoirs of natural gas exist around the world, many in locations isolated from gas-consuming markets. Significant quantities of this "stranded gas" have been liquefied and transported to various 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 convert the methane to high quality liquid fuels using the Fisher-Tropsch (F-T) process. As with coal liquefaction, F-T based GTL results in clean fuels, ready for use in existing end-use equipment with only modest finishing and blending. This gas-to-liquids process has 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 Fisher-Tropsch process. Modern gasification technologies have been dramatically improved over the years, with the result that over 150 gasifiers are in commercial operation around the world, a number operating on coal. Gas cleanup technologies are well developed and utilized 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 subsequently built a number of larger, more modern facilities in South Africa.[10] Coal liquids from gasification/F-T synthesis are of such high quality that they do not need to be refined. When co-producing electricity, coal liquefaction is believed capable of providing clean substitute fuels at $30 – 35 per barrel.[11]

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 U.S. 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 ("woody") biomass, but these processes are far from economic. Reducing the cost of growing, harvesting, transporting, and converting biomass crops will be necessary.[12]

Hydrogen

Recently, the U.S. National Research Council (NRC) completed a study that included an evaluation of the technical, economic and societal challenges associated with the development of a hydrogen economy.[13] The study concluded that fuel cells must improve by (1) a factor of 10-20 in cost, (2) a factor of five in lifetime, and (3) roughly a factor of two in efficiency. The NRC did not believe that such improvements could be achieved by development of current technologies alone; instead, new concepts (breakthroughs) will be required. In other words, today's technologies do not appear practically viable, and the time scale, or even if there will be an introduction of commercial hydrogen vehicles cannot be predicted.

Three Mitigation Scenarios

Analysis approach

Issues related to the mitigation of problems resulting from 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 have been analyzed:

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

The analysis was simplified to provide transparency and promote understanding. While estimates were approximate, 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, as opposed to analysis of policy actions, e.g., tax credits, rationing, automobile speed restrictions, etc. Physical mitigation included (1) implementation of technologies that can substantially reduce the consumption of liquid fuels (improved fuel efficiency) while still delivering comparable service, and (2) the construction and operation of facilities that yield large quantities of liquid fuels.

The pace that governments and industry choose to mitigate the impacts of the peaking of world oil production is not knowable in advance. As a limiting case, our analysis assumed overnight go-ahead decision-making for all actions, that is, crash programs mandated by governments worldwide. 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. Delayed wedges are composed of two parts. The first is the preparation time needed prior to tangible market impact. In the case of efficient transportation, this is the time 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. The second part of the delayed wedge portrays the growing contribution of fuel saving or enhanced and substitute fuel production.

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

1. The option must produce liquid fuels that can, as produced or as refined, substitute for liquid fuels currently in widespread use, e.g. gasoline, jet fuel, diesel, etc. The end

products will, thus, be compatible with existing distribution systems and end-use equipment. Why this criterion? Because there are huge fleets of light duty and heavy-duty vehicles, trains, planes, ships, and other equipment with lifetimes of 15 – 30 years that must be fueled and cannot be scrapped overnight.

2. The option must be capable of liquid fuels savings or production on a massive scale — ultimately millions to tens of millions of barrels per day worldwide.

3. The option must include technology that is commercial or near commercial, which at a minimum requires that the process has been demonstrated on a large scale.

4. Substitute fuel production technologies must be inherently energy efficient, assumed to mean that greater than 50% of process energy input is contained in the clean liquid fuels product[¶].

5. Energy sources or energy efficiency technologies that produce or save electricity were not of interest in this context because commercial processes to convert electricity to clean hydrocarbon fuels do not currently exist.

Contributions 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.A. automobiles in 1975, was one of the most effective of the mandates initiated in response to the 1973-74 oil embargo. A similar, more ambitious program will be an essential element in peak oil mitigation.

The fuels production options that we chose to study are enhanced oil recovery, heavy oil/tar sands, coal liquefaction, and gas-to-liquids. The rationale was as follows:

1. Enhanced oil recovery is in commercial use and is applicable worldwide.

2. Heavy oil/oil sands is currently commercial in Canada and Venezuela.

3. Coal liquefaction is a well-developed, near-commercial technology.

4. Gas-to-liquids is commercially viable where the natural gas source is remote from markets.

A number of options were excluded for various reasons. Shale oil can be processed into substitute liquid fuels, but the technology to accomplish that task is not now ready for deployment and commercial scale oil shale plants do not currently exit. Biomass options capable of producing liquid fuels were also not included. Ethanol from biomass is currently utilized in the U.S.A. and Brazilian transportation markets, primarily because it is mandated and/or subsidized. Biodiesel fuel is a subject of considerable current interest, but it too is not yet commercially viable. A major R & D effort might change the biomass outlook, but only if initiated in the near future.

Over 45% of world oil consumption is for nontransportation uses. Fuel switching away from nontransportation uses of liquid fuels is likely to occur, mimicking shifts that have already taken place in recent decades in the U.S. and elsewhere. The time frame for such shifts is uncertain. For significant world scale impact, large substitute energy facilities would have to be constructed, and that would require decade-scale time periods.

Nuclear power, wind and photovoltaics produce electric power, which is not a near-term substitute fuel in transportation equipment that requires liquid fuels. In the long-term future 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 would be speculative at this time.

Modeling world oil supply/demand

It is not possible to predict with certainty when world conventional oil peaking will occur or how rapidly production will decline after the peak. Therefore, our analysis did not stipulate a date for peaking. Instead peaking was assumed at year zero, and the analysis considered effects of employing mitigation strategies from 20 years before to 20 years after peaking. A shape for world oil peaking was also required, and the pattern of the U.S.A. Lower states 48 production pattern was used because Lower 48 oil production represents what actually happened in a large, complex oil province over the course of over five decades.

For our analysis, world production at peaking was taken as 100 MM bpd, which is 16 MM bpd above the current 84 MM bpd world production. If peaking were to occur in the next year or two, the 100 MM bpd would be high; if peaking occurs at 125 MM bpd at some future date, the 100 MM bpd assumption would be low. Since ours were rough estimates, a 100 MM bpd peak represents a credible assumption for this kind of analysis. The selection of 100 MM bpd is not intended as a prediction of magnitude or timing; its use is for illustrative purposes only.

Another important variable is future world oil demand growth. The World Energy Council stated: "Oil demand is projected to increase at about 1.9% per year rising from about 75.7 million b/d in 2000 (actual) to 113-115 million b/d in 2020 — an increase of about 37.5-39.5 million b/d.".[14] Recent trends indicate a 3+ percent per year world oil demand growth, driven in part by rapidly increasing oil consumption in China and India. However, a 3+ percent growth rate on a continuing basis seems excessive. On this basis, a two percent long-run hypothetical, healthy economy demand after peaking was assumed. This extrapolation of demand after peaking provides a reference that facilitates calculation of supply shortfalls. This assumption has the benefit of simplicity, but it ignores the real-world feedback of oil price escalation on increasing demand, which is sure to happen but will be extremely difficult to forecast.

It should be noted that some analysts have projected world oil production decline rates of 3 – 8%, well above the 2% assumed in our analysis.[15-17] Such higher decline rates would make the mitigation problem much more difficult.

Results of crash program mitigation

The results of our analysis, derived by comparing the likely decline in world oil production implied by peaking and the timescales required for the mitigation options, were as follows:

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

[¶]The choice of a minimum is subjective. A minimum of 50% seems reasonable, but a higher level is clearly more desirable.

• Initiating a mitigation crash 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.

• Initiating a mitigation crash program 20 years before peaking offers 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 peaking can be minimized. If mitigation were to be too little and/or too late, the world supply/demand balance will be achieved through massive demand destruction (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 soon 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 U.S.A. and the world.

The world has never confronted a problem like this, and the failure to act on a timely basis is almost certain to have major 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.

Concluding Remarks

Over the past century, world economic development has been fundamentally shaped by the availability of abundant, low-cost oil. Previous energy transitions (wood to coal, coal to oil, etc.) were gradual and evolutionary as a result of the convenience, availability, and efficiency of the new fuel, not the lack of availability of the fuel being replaced. In contrast, oil peaking will be abrupt and revolutionary and result in shortages and economic dislocation. The world has never faced a problem like this. Without massive mitigation at least a decade before the fact, the problem will be pervasive and long lasting.

Oil peaking represents a liquid fuels problem, not an "energy crisis" in the sense that term has often been used. Accordingly, mitigation of declining world oil production must be narrowly focused, at least in the near-term. A number of technologies are currently available for immediate implementation once there is the requisite determination to act. Governments worldwide will have to take the initiative on a timely basis, and it may already be too late to avoid considerable economic, social, and political discomfort or worse. Countries that dawdle will suffer from lost opportunities, because in every crisis, there are always opportunities for those that act decisively.

In closing, we note that initiation of the crash programs described herein may not be currently possible, because the worldwide technical talent and industrial capabilities do not now exist. In addition, the competition for investment funding from the financial community will likely be fierce. We invite others to provide more informed estimates of how rapidly such crash programs might be practically implemented in light of existing worldwide capabilities.

Literature Cited

1. Hirsch RL, Bezdek R, Wendling.R. *Peaking of world oil production: impacts, mitigation, & risk management.* Department of Energy National Energy Technology Laboratory. February 2005.
2. US. Department of Energy, Energy Information Administration. *Intl Energy Outlook* – 2005; July, 2005.
3. Aleklett, K. & Campbell, C.J. *The Peak and Decline of World Oil and Gas Production.* Uppsala University: Sweden; ASPO Web site www.peakoil.net. 2003.
4. U.S. Department of Energy, Energy Information Administration. *Latest Oil Supply Disruption Information.* eia.doe.gov; 2004.
5. U.S. Department of Energy, Energy Information Administration. *World Oil Market and Oil Price Chronologies: 1970-2003;* March 2004.
6. U.S. Department of Energy, Energy Information Administration. *Global Oil Supply Disruptions Since 1951;* 2001.
7. U.S. Department of Energy, Energy Information Administration. *Annual Energy Review*. 2002.
8. U.S. Department of Energy, Energy Information Administration, *International Petroleum Monthly*; April 2004.
9. Williams B. Heavy hydrocarbons playing key role in peak oil debate, future supply. *Oil and Gas J.* 2003.
10. Kruger P du P. *Startup Experience at Sasol's Two and Three.* Sasol. 1983.
11. Gray D. et al. *Coproduction of Ultra Clean Transportation Fuels, Hydrogen, and Electric Power from Coal.* July, 2001. Mitretek Systems Technical Report MTR: 2001:43.
12. Smith S.J. et al. *Near-Term US Biomass Potential*. PNWD-3285. Battelle Memorial Institute. January, 2004.
13. National Research Council. *The Hydrogen Economy: Opportunities, Costs, Barriers and R & D Needs*. National Academies Press. 2004.
14. Hydrocarbon Resources: Future Supply and Demand. *World Energy Council - 18th Congress*: Buenos Aires: Argentina; October, 2001.
15. Al-Husseini SI, Saudi Aramco. *A Producer's Perspective on the Oil Industry. Oil and Money Conference*. London. October 26, 2004.
16. Hakes, J. Long Term World Oil Supply. EIA. April 18, 2000;
17. ExxonMobil. *Energy Trends, Greenhouse Emissions and Alternate Energy* Report. February, 2004.
18. Bakhtiari AMS. World oil production capacity model suggests output peak by 2006-07. *Oil and Gas J*. 2004;24.
19. Simmons MR. ASPO Workshop. Paris, France. May 26, 2003.
20. Skrebowski C. Oil field mega projects - 2004. *Petroleum Review*. January 2004.
21. Deffeyes KS. *Hubbert's Peak-The Impending World Oil Shortage*. Princeton University Press; 2003.

22. Goodstein D. *Out of Gas - The End of the Age of Oil*. W.W. Norton; 2004.
23. Campbell CJ. *Industry urged to watch for regular oil production peaks. depletion signals. Oil and Gas J*. July 14, 2003.
24. *Drivers of the Energy Scene*. World Energy Council; 2003.
25. Pang Xiongqi. The challenges brought by shortages of oil and gas in china and their countermeasures. *ASPO Lisbon Conference*. May19–20; 2005.
26. Laherrere J. *Seminar Center of Energy Conversion*. Zurich: Switzerland. May 7, 2003.
27. DOE EIA. *Long Term World Oil Supply.* April 18, 2000.
28. Jackson P. et al. *Triple Witching Hour for Oil Arrives Early in 2004 - But, As Yet, No Real Witches. CERA Alert*. April 7, 2004.
29. Davis G. *Meeting Future Energy Needs.* The Bridge. National Academies Press. Summer 2003.