Commission Briefing Paper 4C-06

Assessment of Conventional, Non-Conventional, and Alternative Fuels' Ability to Meet Transportation Energy Demand

Prepared by: Oak Ridge National Laboratory
Date: January 10, 2007

Introduction

This paper is part of a series of briefing papers prepared for the National Surface Transportation Policy and Revenue Study Commission authorized in Section 1909 of SAFETEA-LU. The papers are intended to synthesize the state-of-the-practice consensus on the issues that are relevant to the Commission's charge outlined in Section 1909, and will serve as background material in developing the analyses to be presented in the final report of the Commission.

This paper presents information on the adequacy of global *conventional* oil resources to supply the energy needs of a growing world transportation system and considers the adequacy and other important issues associated with use of unconventional sources of energy. The definition of conventional oil resources is not fixed but changes with advancing technology and economic factors. First, global and national trends in transportation demand and their implications for energy use are reviewed. Second, the ability of traditional energy sources (i.e., conventional petroleum) to supply a growing transportation demand is considered. This introduces the controversial subject of oil peaking. Third, the feasibility of alternatives, including alternative fossil energy sources, biofuels, hydrogen, and energy efficiency improvement are examined with respect to their quantities, costs, technological readiness and environmental impacts. Finally, the question of the timeframes for transitions to large-scale use of alternative transportation fuels is explored.

Background and Key Findings

Today, petroleum supplies more than 95% of the energy required by the world's motorized transportation systems, and transportation accounts for most of the world's petroleum consumption. The world oil market is a truly global market in which the members of the Organization of Petroleum Exporting Countries (OPEC) play a special role as an imperfect monopolistic cartel owning 70% of the world's proven reserves and more than half of the world's estimated ultimate resources of conventional oil. Before 2050, it is virtually certain that the world's transportation systems will require substantial quantities of energy from what are today considered unconventional sources. There is growing support for the view that the rate at which *conventional* oil can be supplied will reach a peak and then either plateau or decline before mid-century. This perspective can be found in projections by ExxonMobil Corporation and the International Energy Agency (IEA, 2006a), as well as the Association for the Study of Peak Oil (ASPO, 2007). Should conventional oil production either peak or plateau, a growing gap will emerge between transportation's increasing demand for energy for mobility and conventional oil supply. If world mobility is to continue to expand the gap will have to be filled by unconventional resources. To some extent, such developments are already underway in the production of Canadian oil sands and Venezuelan heavy oil.

- Driven by growing incomes and national products, global passenger and goods mobility is likely to more than double by 2050.
- Between now and 2050, production of *conventional* oil will peak or reach a plateau but there is great uncertainty about when this will happen and how steep the decline will be. There is a growing consensus that conventional oil production outside of OPEC will peak within the next decade, creating the potential for higher and more volatile oil prices.
- Unconventional fossil hydrocarbon and carbon resources, in the form of oil sands, extra-heavy oil, coal and oil shale can be converted to conventional transportation fuels at costs comparable to oil prices seen over the past three years. These resources are more than adequate to supply the world's transportation energy needs through mid-century and beyond. Forecasts by the IEA and Energy Information Administration (EIA) expect unconventional sources to provide between 5% and 20% of world petroleum fuel demand by 2030.
- Conventional transportation fuels made from unconventional fossil energy sources would be highly compatible with existing fuel distribution infrastructure, vehicle technologies, and emissions standards.
- Liquid fuels from biomass could make a significant contribution to supplying transportation energy (perhaps as much as 30% for the United States) but biomass resources are inadequate to supply all of transportation's energy requirements.
- Unless upstream carbon emissions were captured and sequestered, converting unconventional fossil carbon resources to conventional fuels would increase well-to-wheel carbon emissions by 10% to 100% (depending chiefly on the resource) and would greatly expand the quantity of fossil carbon that could be put into the atmosphere.
- Investments in unconventional transportation fuel production will be risky. Compared to conventional oil production, larger capital investments will be required and production costs will be higher.
- Large-scale substitution of alternative energy resources for petroleum could also be driven by a need to significantly reduce greenhouse gas emissions from transportation vehicles. The most promising candidates appear to be biomass fuels and hydrogen and/or electricity derived from renewable sources or from fossil fuels with carbon capture and sequestration. This important issue is not addressed in this briefing paper.

Trends in Transportation Demand and Energy Use

Continued economic growth, especially rising per capita incomes, are expected to drive rapid growth in world passenger and freight demand. The World Business Council for Sustainable Development's (WBCSD, 2004) *Mobility 2030* study projects that passenger-kilometers of travel will increase at an average annual rate of 1.7% through 2050, while freight ton-kilometers will grow at 2.3%/year. Growth rates in developing economies are expected to be at least twice as fast as in the developed economies. The result is more than a doubling of passenger-kilometers and nearly a tripling of ton-miles. The WBCSD study does not expect the modal mix of transport activity to change dramatically. Highway vehicles are expected to continue to be the predominant mode of transport, despite somewhat faster growth in air and rail freight traffic.

Worldwide transportation fuel use is projected to double despite significant energy efficiency gains. The *Mobility 2030* study projects reductions in energy intensity of 18%, 29% and 29% for light-duty vehicles, heavy-duty trucks, and aircraft, respectively by 2050. The IEA (2006b, p.

253) asserts that a 40% improvement in the fuel economy of gasoline vehicles could be achieved at low costs by 2050. Such efficiency gains, though extremely valuable, are not nearly enough to offset the projected activity increases of 123%, 241% and 400%, respectively, for these vehicle types. By 2050, global transportation fuel use is projected to reach 5 trillion liters of gasoline equivalent energy, nearly 180 exajoules, annually (Figure 1).

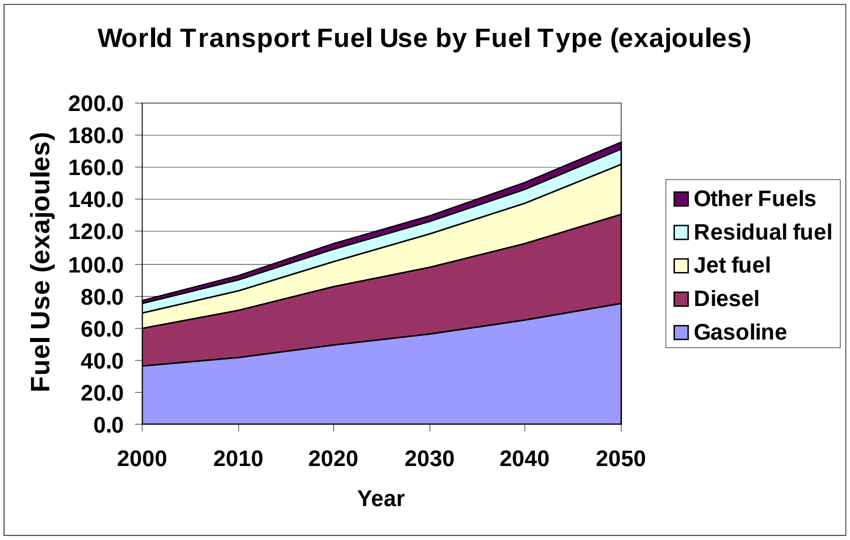

Figure 1. WBCSD Projection of World Transportation Fuel Use by Fuel Type to 2050
Source: Eads, 2006.

Conventional and Unconventional Resources

By the year 1995, the world's economies had consumed a cumulative total of 710 billion barrels of oil since the beginning of the oil age. Just 10 years later, in 2005, world cumulative consumption amounted to 979 billion barrels. *One fourth of all the oil ever consumed by humans was consumed in the past ten years.* This startling fact needs to be placed in the context of how much oil remains to be produced, yet it clearly illustrates the acceleration of global oil consumption, driven chiefly by rising transportation energy demand. The IEA estimates that transportation will account for 63% of the growth of petroleum consumption between now and 2030 (IEA, 2006a, p. 88).

Conventional petroleum is defined as liquid hydrocarbons of light and medium gravity and viscosity in porous and permeable reservoirs. Unconventional oil consists of deposits with a density greater than water or with high viscosity (> 10,000 cP) or found in tight formations. Conventional petroleum will flow in underground reservoirs and can therefore be produced with conventional drilling methods. It also has a relatively high hydrogen-to-carbon ratio and so requires relatively little addition of hydrogen to be converted to transportation fuels such as gasoline and distillate. About two-thirds to one-half of the petroleum in a reservoir (depending on reservoir conditions and production methods) remain in the ground when production from that reservoir ceases. Conventional petroleum recoverable by enhanced recovery methods, as well as liquid hydrocarbon by-products of natural gas production, is often included in the definition of conventional petroleum.

How much oil is left? The most comprehensive, scientific survey of world conventional petroleum resources to date was completed by the U.S. Geological Survey (USGS) in 2000. USGS geologists estimated the quantities of conventional oil, gas and natural gas liquids (NGLs) they judged to be "technically recoverable" and to have the potential to be added to reserves by 2025 (Ahlbrandt et al., 2005, p. 1). The estimates include both undiscovered oil and reserve growth for discovered fields. Because neither can be specified precisely, the USGS estimates are probability distributions rather than single values. Considering only crude oil, the mean estimate of ultimate resources is 3.0 trillion barrels with a 95% probability of at least 2.2 trillion barrels and a 5% probability of more than 3.9 trillion (Table 1). Ultimate resource estimates also include cumulative consumption to date, as well as proven reserves. Thus, the mean estimate of remaining crude oil in 2005 is 2,994 – 979 = 2,015 billion barrels.

Table 1. USGS 2000 Estimates of World Conventional Petroleum Resources through 2025

	Oil				Natural Gas Liquids				Total Petroleum			
	95%	50%	5%	Mean	95%	50%	5%	Mean	95%	50%	5%	Mean
Undiscovered	394	683	1202	725	101	196	387	214	495	879	1589	939
Res. Growth	255	675	1094	675	26	55	84	55	281	730	1178	730
Proved Res.	884	884	884	884	75	75	75	75	959	959	959	959
Cum Prod.	710	710	710	710	7	7	7	7	717	717	717	717
TOTAL	2244	2953	3890	2994	210	334	553	351	2454	3286	4443	3345

Source: USGS, 2000, as modified to include natural gas plant liquids by Greene et al., 2003. Units: billions of barrels. Components may not add to totals due to rounding.

How long will the oil last? Unfortunately, dividing the estimated 2 trillion barrels of crude oil remaining by the current annual production rate of 26.5 billion barrels produces not an estimate of the life of conventional oil resources but yet another measure of their size denominated in unusual units: years. To be useful to the world's transportation system oil must be produced at the rate it is needed, a rate that will continue increasing through 2050. The key insight of peak oil advocates is that the critical question is not "When will we run out of oil?" but rather "When will we no longer be able to increase production?" Disciples of M. K. Hubbert, a Shell geologist who correctly predicted the peaking of U.S. crude oil production in 1970, believe that oil production peaks when approximately half of the ultimately recoverable oil in a reservoir has been produced. Peaking of oil production at roughly the 50% point has been observed in many regions of the world.

Outlook for Petroleum Supply

When will conventional oil production peak? On this subject there is considerable disagreement among experts. The key areas of disagreement are listed below (Greene et al., 2006).

1. How much conventional oil there really is (see Table 1).
2. How much OPEC really has and how rapidly they are willing to produce it.
3. How much unconventional oil can be used to replace conventional oil and at what rate.
4. How rapidly conventional oil production will decline once the peak has been reached.

The ASPO takes the position that the USGS has generally overestimated world oil resources; that OPEC has less oil than it claims to have and that rates of decline once the oil peak is reached will be consistent with rates of decline observed in regions where oil production has already peaked. Given these assumptions, a peak in global petroleum production is predicted just after 2010 (Figure 2). Peak oil advocates do not believe that unconventional resources will be able to fill the growing gap and, as a result, expect drastic demand destruction.

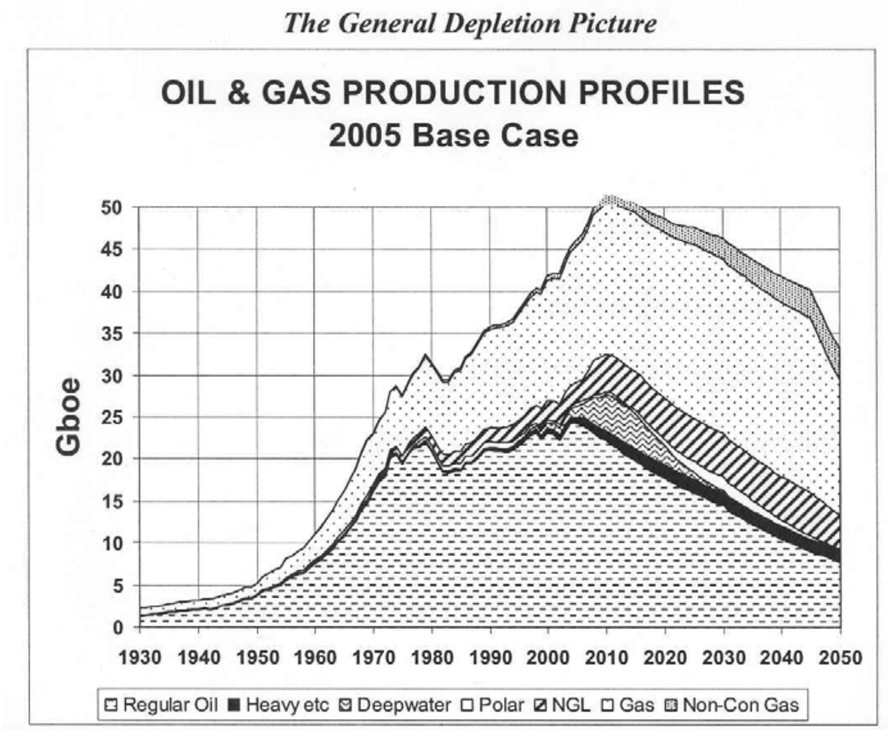

Figure 2. ASPO Estimates of Global Oil and Gas Production to 2050 (ASPO, 2007)
Gboe = billion barrels of oil equivalent

Government and industry forecasts are more optimistic. They assume much larger world oil resources and expect conventional oil supply to be increasingly augmented by supplies from unconventional sources such as oil sands, extra-heavy oil, gas-to-liquids and coal-to-liquids. These forecasts do not see oil shale becoming a significant factor before 2030. While they project substantial increases in OPEC output, the increases are on the order of half of what was predicted before the oil price increases of the past three years.

The EIA's *International Energy Outlook 2006* (IEO2006) Reference Case projects that world oil consumption will increase from 80 million barrels per day (mb/d) in 2003 to 118 mb/d in 2030, despite an oil price of $57/bbl (2004 $) (EIA, 2006, ch. 3). OPEC is expected to supply an additional 14.6 mb/d, while non-OPEC countries supply 23.7 mb/d, of which almost half (11.5 mb/d) is from unconventional sources. This represents a dramatic scaling back of expectations for OPEC production from the IEO2005. The IEO2005 (which projected only to 2025) expected OPEC supply to increase by 24 mb/d by 2025, while the IEO2006 projects only an 11.8 mb/d expansion for 2025. Consequently, higher world oil prices are projected. The IEO2006 low oil price, reference and high oil price cases project oil prices of $34, $57 and $96/bbl, respectively in 2030. The corresponding IEO2005 projections were $21, $35 and $48/bbl (for 2025).

Unlike the EIA, the IEA *does* expect non-OPEC oil supply to peak well before 2030 (Figure 3). However, the IEA foresees not a sharp peak but a plateau.

"Outside OPEC, conventional crude oil production in aggregate is projected to peak by the middle of the next decade and decline thereafter, though this is partly offset by continued growth in output of NGLs [i.e., Natural Gas Liquids]." (IEA, 2006a, p. 94).

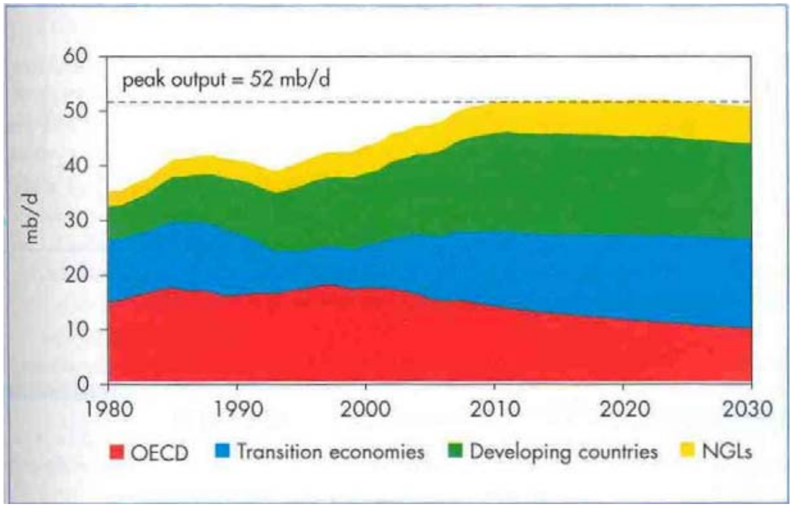

Figure 3. Non-OPEC Crude Oil and NGLs Production, World Energy Outlook 2006
(Source: IEA, 2006a, figure 3.6, p. 95)

This view is shared by ExxonMobil, whose 2004 projection of world petroleum supply shows non-OPEC supply peaking in the vicinity of 2015 (Figure 4). Like the EIA and IEA projections, the ExxonMobil projection assumes that OPEC will fill the gap between non-OPEC supply of liquid fuels and anticipated world demand.

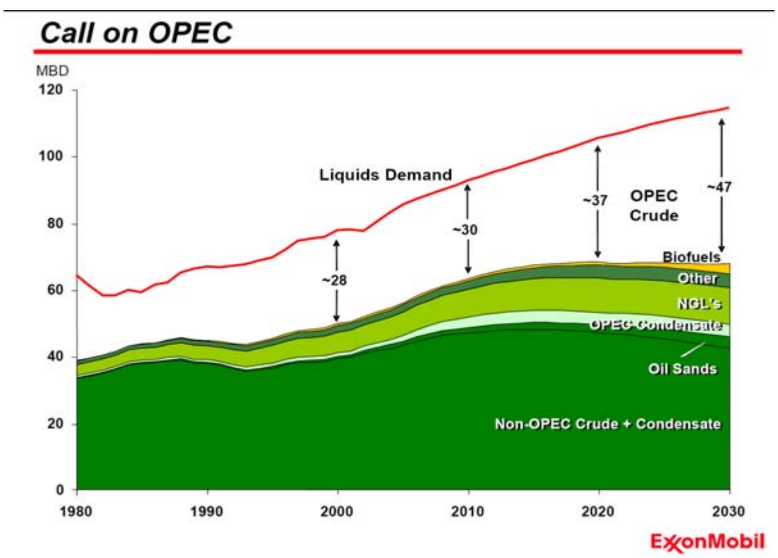

Figure 4. ExxonMobil Projections of World Petroleum Supply to 2030 (Tillerson, 2004)

The EIA's more recent oil price projections reflect the view that OPEC may fill the gap but only at much higher oil prices than previously expected. This view is consistent with the observation that the peaking of non-OPEC supply will magnify the cartel's market power, and also with careful analysis of production levels that best serve OPEC's economic interests (Gately, 2004). It is based on EIA's judgment that OPEC is less willing to aggressively expand production than previously thought and does not reflect any change in EIA's assessment of OPEC's oil resources (EIA, 2006, p. 25). OPEC's actions are critically important since lower OPEC output will tend to raise world oil prices and hasten the transition to other energy sources while volatile oil prices will increase the risk of investing in alternatives to petroleum.

Neither the EIA nor the IEA oil market projections attempt to predict price volatility. Yet the history of world oil prices since the first "energy crisis" in 1973-74 shows that volatility has been a dominant feature of world oil prices for the past three decades (Figure 5). Until 1973, the United States was the world's largest oil producer. But U.S. crude oil production peaked at 9.64 mb/d in1970, never to return to that level. The peaking of U.S. supply conferred additional market power on the OPEC cartel, power it has used inconsistently ever since to influence world oil prices. If world conventional oil production outside of OPEC peaks, this too will add to the cartel's market influence. While this does not guarantee either higher or more volatile oil prices in the future it creates the potential for both.

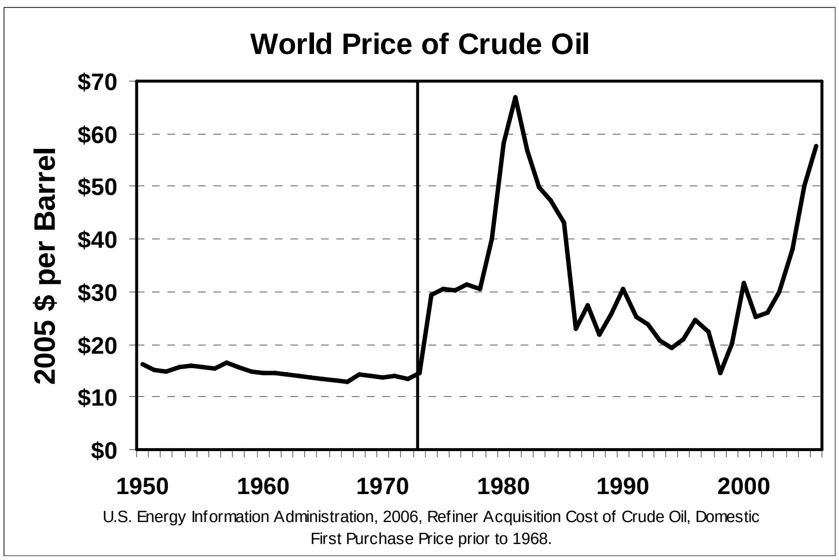

Figure 5. World Crude Oil Prices Since 1950

Unconventional Fossil Hydrocarbon Resources and Coal

The quantities of unconventional fossil hydrocarbons (including gas-to-liquids and coal-to-liquids) from which transportation fuels can be made are enormous. Because unconventional resources are by definition either technologically or economically impractical at the present time, there is much greater uncertainty about their quantities. Unconventional petroleum resources are generally divided into three categories: oil sands, extra-heavy oils and oil shale. Oil sands and extra-heavy oil have such high viscosities that they will not flow and thus require special extraction methods. Because they lack the lighter, more volatile components needed in motor fuels, they also require a much greater degree of upgrading than conventional petroleum. However, both oil sands and extra-heavy oil are produced today in relatively small quantities leading some to consider them conventional resources.

Unconventional petroleum resources appear to be highly geographically concentrated. Resources of extra-heavy oil are concentrated in Venezuela, which has roughly 1.2 trillion barrels in place, with 270 billion barrels recoverable with current technology (IEA, 2006b, p. 265). Oil sands resources are concentrated in Canada; whose 1.6 trillion barrels (310 recoverable) represents 80% of the world's known occurrences. Oil shale occurrences are concentrated in the United States, which has about 500 billion barrels of medium quality oil shale and about 1 trillion barrels of low quality oil shale.

The IEA expects production of unconventional oil to increase from about 1.6 mb/d today to 9 mb/d (from 2% to 8% of global supply) by 2030 (IEA, 2006a, p. 97). Most of the increase is expected to come from Canadian oil sands production (from 1 mb/d in 2005 to 5 mb/d in 2030), with smaller contributions from gas-to-liquids (2.3 mb/d in 2030) and coal-to-liquids (750 kb/d), mainly from China. The EIA projects an increase of unconventional oil production from 1.8 mb/d in 2003 to 11.5 mb/d in 2030, still just 10% of total liquids production in that year. Production of unconventional petroleum would increase to 16.3 mb/d in 2030 in EIA's high world oil price case (Figure 6).

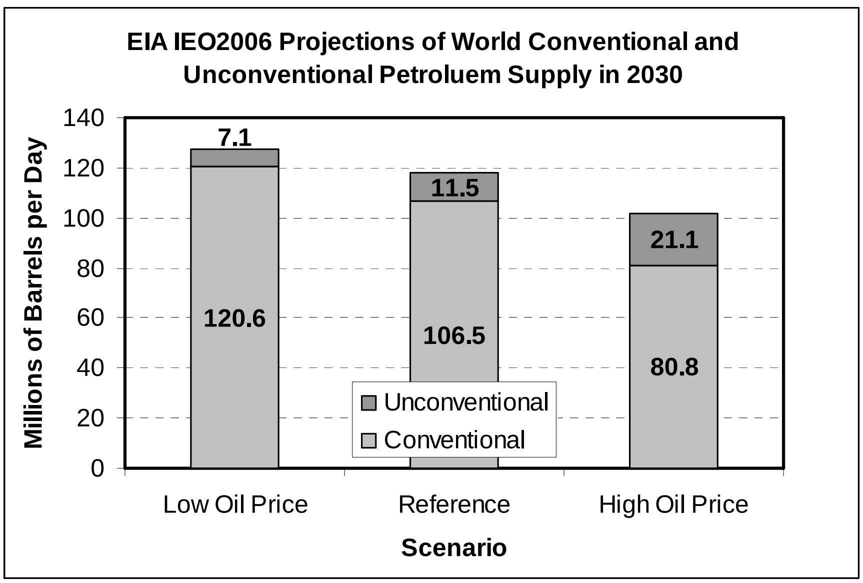

Figure 6. EIA IEO2006 Projections of World Conventional and Unconventional Petroleum Supply in 2030

Conventional transportation fuels can be synthesized from coal or natural gas using established technology and at costs below today's oil prices ($35-$40/bbl: IEA, 2006b, p. 270). The cost of converting natural gas to liquid fuels is highly sensitive to the price of natural gas. Given this, gas-to-liquids projects will likely be limited to "stranded" gas reserves that do not have access to markets via pipeline and are not large enough to justify an LNG terminal. The IEA estimates that there are 6,000 exajoules (almost 1 trillion barrels of oil equivalent) of stranded gas in the world, more than half of which is in the Middle East.

Conversion of coal into liquid fuels via gasification and catalytic synthesis was first accomplished in the early twentieth century. Today, Sasol, a South African oil company, operates two coal-to-liquid plants with capacities of 150 kb/d that produce 80% synthetic diesel fuel and 20% synthetic naptha. The world's proved reserves of coal amount to 1 quadrillion short tons, more than enough to supply the world's transportation system through the end of the century. However, well-to-wheel carbon dioxide emissions are more than doubled by coal-to-liquid fuels unless the carbon produced in the coal-to-liquid conversion is captured and stored. Two-thirds of the carbon in the coal is released as carbon dioxide in the fuel production process (IEA, 2006b, p. 270).

Biofuels, Hydrogen and Electricity

Fuels derived from biomass, especially ethanol, are already widely used in transportation vehicles in the United States, Brazil and many other countries. More than 4 million vehicles already on U.S. highways are capable of running on a mixture of 85% ethanol and 15% gasoline. All conventional gasoline vehicles can use ethanol blends of up to 10%. Furthermore, biomass can be made into many other types of fuel and even into gasoline or diesel via gasification and Fischer-Tropsch synthesis.

Biomass fuels alone are not able to supply all of transportation's energy needs. A recent assessment by the U.S. Departments of Energy and Agriculture concluded that the land resources of the United States were capable of producing a sustainable supply of biomass sufficient to displace 30 percent of current U.S. petroleum consumption by 2030 (Perlack et al., 2005). Questions remain about the economic practicality of supplying 30% of U.S. transportation energy with biomass and technological advances are required, as well. The global potential for biofuels is smaller.

> "Conventional biofuel production requires about 1% of all arable land and yields about 1% of global transportation fuels. If 100% of the fuel requirements for world transport were derived from conventional biofuels, the land requirement would reach 1.4 gigahectares, an amount equivalent to all of the world's arable land." (IEA, 2006a, p. 289)

Increased productivity and a switch to energy crops that can be grown on marginal land could change this picture somewhat.

There is no doubt that enough hydrogen could be produced to power all of the world's surface transportation vehicles. Hydrogen can be produced via gasification from any fossil energy resource and from biomass. It can be produced from water via electrolysis or high-temperature thermo-chemical processes. But serious questions remain about the technical feasibility and economic practicability of a hydrogen-powered transportation system (IEA, 2006b). Unlike unconventional petroleum fuels, hydrogen-powered transportation would require an entirely new fuel supply infrastructure. Hydrogen storage, especially on board vehicles, remains a difficult technical challenge, as does reducing the cost of the fuel cell stacks that convert hydrogen to electricity to power electric motors. Analyses of the timing of a potential transition to hydrogen-powered light-duty vehicles indicate that if the ambitious technical goals of government and industry R&D programs are met, hydrogen vehicles could begin a significant market penetration by 2020 and could replace most light-duty vehicles by 2050. Such scenarios, however, require dramatic technological breakthroughs and strong policies to insure the co-evolution of the hydrogen powered vehicle fleet and the infrastructure to support it (Leiby et al., 2006).

Electricity, which can also be produced from a wide array of energy sources, also has the potential to supply a significant amount of transportation energy. The key barrier to widespread use of electricity in surface transport remains the difficulty of storing sufficient amounts of energy on-board the vehicle. Progress in battery technology has been substantial, yet cost and energy storage remain formidable barriers to widespread market acceptance (IEA, 2006b, p. 313). The market success of hybrid vehicles has led to interest in "plug-in" hybrids that can take electricity from the grid but still have unlimited range provided by their internal combustion engines. Plug-in hybrids necessarily require larger battery packs than hybrids powered by petroleum fuels and reducing the cost and improving the performance of batteries remains the key technological hurdle that must be overcome to achieve market acceptance.

Capital Investment, Lead times, Risks

The IEA has estimated that the capital investments required to provide additional conventional and unconventional oil to satisfy world demand through 2030 will amount to $4.3 trillion, $164 billion per year (IEA, 2006a, p. 102). Upstream investment accounts for 73% of the total estimated requirements, and 90% of upstream investment is for field development and exploration. Three quarters of that total goes to maintaining production levels in existing fields in the face of natural decline as resources are depleted. In general, production of synthetic petroleum from unconventional sources is more capital intensive than conventional petroleum production. The IEA cautions that there is considerable uncertainty in their estimates, due in part to a lack of reliable information on production decline rates.

Hirsch et al. (2005) explored the rates at which alternative energy sources could be brought on line to fill an expanding gap between growing petroleum demand and decreasing petroleum consumption after an oil peak. The estimated lead times required until the first supplies could be brought on line and the impact after ten years in mb/d are shown in Table 2. The estimates are premised on an unhindered crash program and assume a linear increase in supply once production begins. There is great uncertainty about the rate at which the supply of alternative energy sources could be brought on line. Very little research has been done on the speed at which transitions to alternative transportation fuels can be accomplished.

The estimated lead times shown in Table 2 are intended to reflect crash programs under crisis conditions. In reality the lead times required for bringing alternative energy sources to market will depend on several factors that are very difficult to predict.

1. Lead times for resource development and conversion plant construction
2. Delays caused by local community or environmental interest group opposition, if any
3. Possible delays caused by failure to anticipate the quantity of new supply required,
4. Possible delays caused by risk aversion of energy companies in a volatile world oil market
5. Economic incentive to supply substitutes, i.e., the price of oil
6. Readiness of technology for development of unconventional resources and their conversion.

Table 2. Estimated Lead Times and Impacts of Petroleum Replacements

	Lead Time to First Impact	Impact 10 Years after Production Begins

Category	(years)	(mb/d)
Vehicle efficiency	3	3
Gas-to-liquids	3	2
Heavy oils / Oil sands	3	8
Coal-to-liquids	4	5
Enhanced oil recovery	5	3

Hirsch et al., 2005, Table A-2.

References

Ahlbrandt, T.S., R.R. Charpentier, T.R. Klett, J.W. Schmoker, C.J. Schenk and G.F. Ulmishek. 2005. *Global Resource Estimates from Total Petroleum Systems*, AAPG Memoir 86, American Association of Petroleum Geologists, Tulsa, Oklahoma.

(ASPO) Association for the Study of Peak Oil. 2007. Newsletter No. 73, January 2007, available on the world wide web at www.peakoil.net .

Eads, G. 2006. "Worldwide Demand for Mobility and Petroleum," presentation at the *DOE/EPA Workshop on Modeling the Oil Transition*, Washington, DC, April 20-21. Available on the Internet at http://cta.ornl.gov/oiltransitions.

(EIA) Energy Information Administration. 2006. *International Energy Outlook 2006*, DOE/EIA-0484(2006), Washington, DC, June.

Gately, D. 2004. "OPEC's Incentives for Faster Output Growth," *The Energy Journal*, vol. 25, no. 2, pp. 75-96.

Greene, D.L., J.L. Hopson and J. Li. 2003. *Running Out of and Into Oil: Analyzing Global Oil Depletion and Transition through 2050*, ORNL/TM-2003/259, Oak Ridge National Laboratory, Oak Ridge, Tennessee, October.

Greene, D.L., J. Hopson and J. Li. 2006. "Have We Run Out of Oil Yet? Oil Peaking Analysis from an Optimist's Perspective," *Energy Policy*, vol. 34, no. 5, pp. 515-531.

Hirsch, R.L., R. Bezdek and R. Wendling. 2005. "Peaking of World Oil Production: Impacts, Mitigation, & Risk Management," SAIC, February.

(IEA) International Energy Agency. 2006a. *World Energy Outlook 2006*, OECD/IEA, Paris.

(IEA) International Energy Agency. 2006b. *Energy Technology Perspectives 2006: Strategies and Scenarios to 2050*, OECD/IEA, Paris.

Leiby, P.N., D.L. Greene, D. Bowman and E. Tworek. 2006. "Systems Analysis of the Hydrogen Transition with HyTrans," Paper No. 06-2538, presented at the 85th Annual Meeting of the Transportation Research Board, January 2006, Washington, DC, *Transportation Research Record*, forthcoming.

Perlack, R.D., L.L. Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes, D.C. Erbach. 2005. *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, DOE/GO-102995-2135, ORNL/TM-2005/66, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Tillerson, R. 2004. "ExxonMobil: Taking On the World's Toughest Energy Challenges," a presentation to the Merrill Lynch Global Energy Conference, New York, November 3.

(USGS) U.S. Geological Survey. 2000. *World Petroleum Assessment 2000—Description and Results*, USGS Digital Data Series-DDS-60, Department of the Interior, Reston, VA

(WBCSD) World Business Council for Sustainable Development. 2004. *Mobility 2030: Meeting the challenges to sustainability*, Geneva, Switzerland; available on the worldwide web at http://www.wbcsd.org/web/mobilitypubs.htm.