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Future Prices and Availability of Transport Fuels

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1. INTRODUCTION

It is a truism that future prices of energy for transportation will be determined by the forces of supply and demand. For transport fuels, these forces have entered a crucial phase that is likely to persist for several decades. Oil production from conventional resources outside of the OPEC countries will peak within a few years. Unconventional fossil resources that can be exploited at current prices, resources whose early development is already well underway, pose an even greater threat to the global climate. To bring these resources to the market at a rate to match the growth in demand for mobility fuels in the developed and developing economies will require massive, risky investments. Serious risks are posed by the environmental acceptability of these fuels and also by the fact that a sudden downturn in world oil prices would turn them into stranded assets.

It is also a truism that no one can accurately predict the price of oil. Today, oil costs $70 per barrel. Ten years ago, it cost less than $20 per barrel. Twenty seven years ago oil prices peaked at $90 per barrel (Figure 1). Thirty-seven years ago oil cost only $10 per barrel and its price had been relatively stable for almost fifty years. Those who carefully craft future oil price scenarios know that they are not predicting but rather attempting to define alternative paths of central tendency. Even the best official oil price projections look nothing like the past thirty-five years of history (Figure 1). It is important to understand why this is so. Since 1972, world oil prices have been strongly and unpredictably influenced by the actions of the OPEC cartel. It is very likely that they will be for the next thirty years, as well.
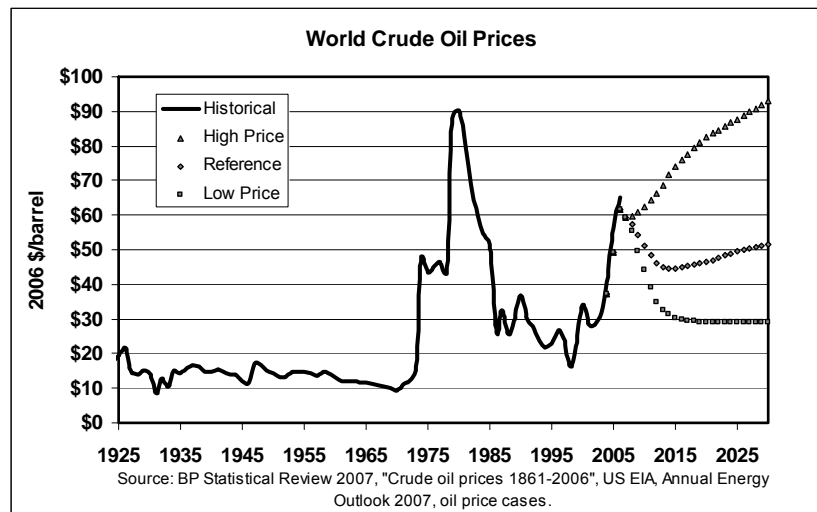

Figure 1. **World Oil Prices: History and Projections**

Two critical factors have joined the OPEC cartel as the key drivers of future transportation fuel prices:

1. Oil peaking and,
2. Climate change.

Oil peaking is real. It is not a figment of a paranoid imagination. When U.S. crude oil output peaked in 1970, the United States was the world's largest producer of crude oil (U.S. petroleum production including natural gas liquids peaked in 1972). Despite the dramatic price increases shown in Figure 1, significant new discoveries and profound technological improvements expanding economically recoverable resources, U.S. petroleum supply never afterwards recovered to its peak level (Figure 2). Many other regions have since gone past their peak (Smith, 2006, counts 60). Peaking of conventional oil production will continue to occur in oil producing regions throughout the world. It must. It rests on the unexceptionable premise that the *rate* of conventional[1] petroleum production cannot continue to *increase* until the last drop is produced.
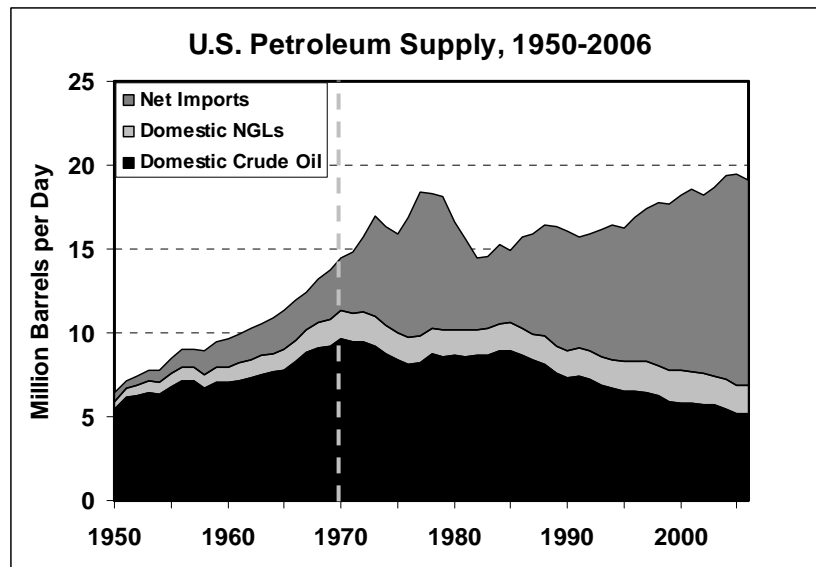

Figure 2. **Peaking of U.S. Petroleum Supply and Imports, 1950-2005**.

The good news is that oil peaking will not mean the end of civilization as we know it. Vast fossil resources exist that can be converted to conventional transportation fuels using proven technology and at prices below the current

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[1] 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 and liquid hydrocarbon by-products of natural gas production are often included in the definition of conventional petroleum. Some now consider Canadian oil sands to be conventional resources but in this report they are classified as unconventional.

world price of oil (IEA, 2006b, pp. 266-271). Indeed, exploitation of Canada's unconventional oil sands resources is well underway. Venezuela has vast reserves of extra-heavy oil in the early stages of exploitation and South Africa has for decades proven that coal can be converted to excellent gasoline and diesel fuel. And then there is oil shale, of which the United States possesses vast quantities. Not only can these fuels be produced at prices the world's economies have demonstrated they are willing to pay, but they are entirely compatible with the existing fuel distribution and vehicle infrastructure. Producing conventional liquid fuels from these sources is more capital intensive and more environmentally disruptive than conventional crude oil production and refining. Even conventional crude oil production has become more capital intensive as energy companies turn to reservoirs in deeper offshore waters and more hostile environments.

The bad news is that all of the unconventional fossil sources, on a well-to-wheel basis, produce significantly more carbon dioxide emissions than gasoline and distillate fuels refined from conventional petroleum: from about 20% more for Canadian oil sands to 100% more for gasoline from coal. As others have pointed out more than a decade ago (e.g., Grubb, 2001), raising atmospheric carbon concentrations to levels likely to cause dangerous climate change depends on our continuing to burn coal and on the exploitation of unconventional fossil resources. If most of the excess CO_2 can be captured and sequestered, the transition to unconventional fossil fuels might conceivably be compatible with climate protection. In any case, coping with the excess carbon emissions will add to the cost and risk of making conventional transportation fuels from unconventional fossil resources.

The very large capital investments required to satisfy the world's growing demand for transport fuels from conventional and unconventional fossil resources will be subject to increasing risk. The International Energy Agency (2006, p. 102) estimates that $4.3 trillion (2005 $) will have to be invested between now and 2030 to meet the world's growing demands for petroleum. If the world takes decisive actions to mitigate climate change, either the carbon emissions from the production of conventional transport fuels from unconventional fossil resources will have to be captured and stored, or they will be subject to stiff carbon taxes. Carbon capture and storage will add significantly to the cost of these fuels, if it is allowed at all. In addition, there will be the risk of falling oil prices. Even with an all-out effort to fill the gap between growing demand and peaking conventional non-OPEC supply, OPEC is likely to retain its current level of market power in world oil markets through 2050 at least (Greene, Hopson and Li, 2005). History has shown that OPEC's behavior can make prices fall as well as rise, creating even greater risk for energy companies weighing investments in developing unconventional fossil resources.

All of this adds up not only to higher prices, but to the likelihood of greater volatility. The world's oil consumers would be fortunate indeed if future oil prices were only high but stable. More likely, oil prices will be highly unstable.

The solution to the problems caused by high and volatile oil prices is likely to be policy-driven technological change. Aggressive pursuit of energy efficiency can extend resources, mitigate greenhouse gas emissions and enhance energy security. Though it may seem counterintuitive, sound greenhouse gas policy should also promote the exploitation of existing conventional oil resources in an environmentally sound way, in order to postpone the transition to more carbon intensive unconventional fossil resources. And, of course, research and development to further expand the envelope of energy efficiency, develop appropriate biomass fuels, and eventually introduce electricity and possibly even hydrogen as energy carriers for transportation is essential to establishing a sustainable energy basis for world transport.

2. GROWING TRANSPORT FUEL DEMAND

The current rate at which the world is consuming conventional petroleum is truly alarming. There is substantial uncertainty about how much conventional oil remains in the world. There is very little uncertainty about how much has already been used. In 1995 cumulative world oil consumption amounted to 710 billion barrels (Ahlbrandt et al., 2005, table 1). Just ten years later in 2005 cumulative consumption amounted to 979 billion barrels. More than one-fourth of all the petroleum consumed throughout all of human history was consumed in the last ten years. The U.S. Secretary of Energy asked the U.S. National Petroleum Council to examine the question of oil peaking. Their report, entitled "Facing the Hard Truths about Energy", noted that if present trends continue the world will consume 1.1 trillion barrels of oil in the next 25 years, *more than has been consumed throughout all history*. This would bring total cumulative consumption in 2030 to 2 trillion barrels, two-thirds of the U.S. Geological Survey's median estimate of the world's ultimate resources of conventional oil (Ahlbrandt et al., 2005).

World oil demand is growing chiefly because of the continuing, slow growth in transport activity in the developed economies and the rapid expansion of motorized transport in developing economies. The IEA projects that primary oil demand will increase by 1.3% per year, from 84 mb/d in 2005 to 99 mb/d in 2015 and 116 mb/d in 2030. Developing economies are expected to account for more than 70% of the increase. The IEA estimates that transportation will account for 63% of the growth of petroleum consumption between now and 2030 (IEA, 2006a, p. 88).

Petroleum demand in the developing world will be driven by the motorization of passenger transport and the continuing growth of international trade. Taking into consideration the likelihood that motor vehicle ownership in developing economies will likely "saturate" at levels well below those of the U.S. or Canada, still Dargay et al. (2007) project that world motor vehicle ownership will increase from about 800 million vehicles today to more than

2 billion in 2030.[2] In 2030, well over half of the world's vehicles are expected to be in non-OECD countries, compared to about one-fourth today. China's vehicle stock is projected to grow to 390 million vehicles by 2030, twenty times its size just five years ago. Depending on how successful China is in its efforts to restrain the growth of motor vehicle fuel consumption, Huo et al. (2007) project that by 2050 China's motor vehicles will consume between 12 and 21 million barrels per day of fuel and emit 2-3 billion metric tons of CO_2 each year.

The World Business Council for Sustainable Development (2004) foresees similar growth in both passenger and freight demand. By 2050 annual passenger kilometers are expected to more than double from just over 30 trillion in 2000 to over 70 trillion by 2050 (an annual rate of 1.7%/year). Freight traffic is expected to more than triple over the same period, growing at an average annual rate of 2.3%/year. 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.
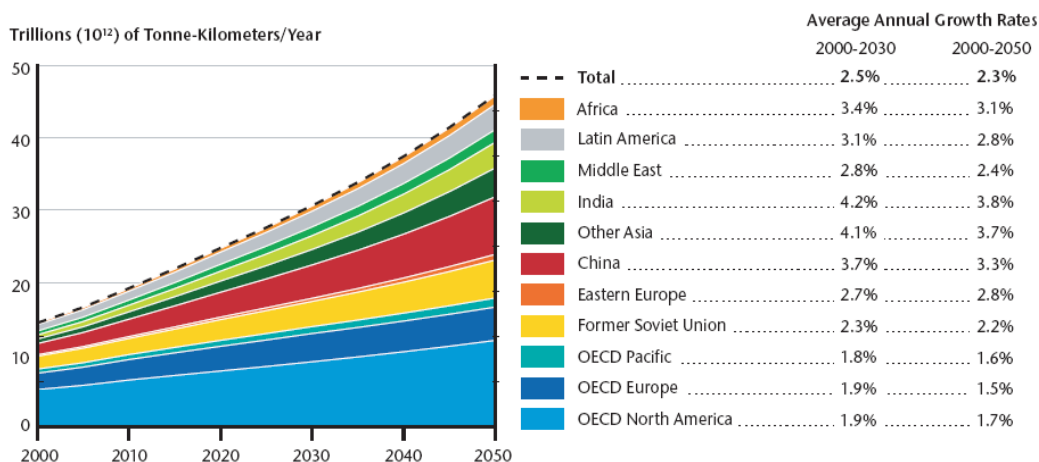
Worldwide transportation fuel use is projected to double by 2050 despite significant energy efficiency gains. The *Mobility 2030* study projects reductions in energy intensity of 18%, 29% and 29% for light-duty vehicles, heavy-duty trucks, and aircraft, respectively by 2050. The IEA (2006b, p. 253) asserts 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.

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[2] Saturate is a poor choice of words. Auto ownership continues to increase even in auto "saturated" economies such as the United States. More accurately, the growth in ownership will slow substantially.

Trillions (10^{12}) of Passenger-Kilometers/Year

		Average Annual Growth Rates	
		2000-2030	2000-2050
– – –	Total	1.6%	1.7%
	Africa	1.9%	2.1%
	Latin America	2.8%	2.9%
	Middle East	1.9%	1.8%
	India	2.1%	2.3%
	Other Asia	1.7%	1.9%
	China	3.0%	3.0%
	Eastern Europe	1.6%	1.8%
	Former Soviet Union	2.2%	2.0%
	OECD Pacific	0.7%	0.7%
	OECD Europe	1.0%	0.8%
	OECD North America	1.2%	1.1%
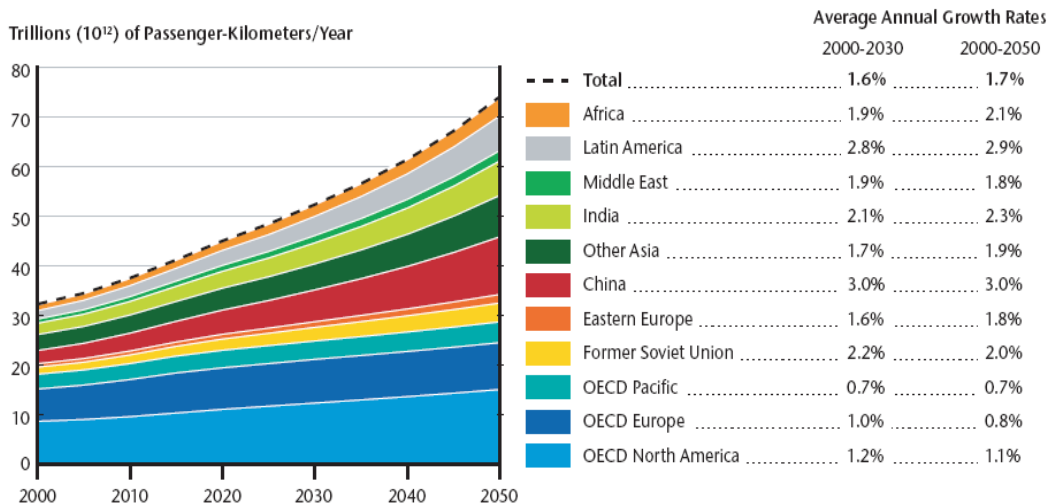
Source:
Sustainable Mobility Project calculations.

Figure 3a. **World Passenger Travel to 2050** (WBCSD, 2004)

Trillions (10^{12}) of Tonne-Kilometers/Year

		Average Annual Growth Rates	
		2000-2030	2000-2050
– – –	Total	2.5%	2.3%
	Africa	3.4%	3.1%
	Latin America	3.1%	2.8%
	Middle East	2.8%	2.4%
	India	4.2%	3.8%
	Other Asia	4.1%	3.7%
	China	3.7%	3.3%
	Eastern Europe	2.7%	2.8%
	Former Soviet Union	2.3%	2.2%
	OECD Pacific	1.8%	1.6%
	OECD Europe	1.9%	1.5%
	OECD North America	1.9%	1.7%

Note:
Excludes air waterborne and pipeline.

Source:
Sustainable Mobility Project calculations.

Figure 3b. **World Freight Traffic to 2050** (WBCSD, 2004)

Rising demand increases the potential for volatility in world oil markets, as will be explained in the following section. The current regime of high oil prices is said to be a demand driven price shock, to distinguish it from the price shocks of 1973-74, 1979-80, and 1990-91 which clearly involved a sudden reduction in oil supply. An unanticipated surge in demand, especially from China and India, clearly contributed to the run-up in prices. Supply constraints also play an important role in the current high price regime. The continued inability of Iraq, with the world's second largest reserves, to increase its oil output certainly helps sustain high prices. Yet the first oil price shock in 1973-74 was preceded by even more rapid growth in world oil demand. World oil demand had been growing at the rate of 7% per year when the Arab OPEC oil

embargo hit. Equally significant is the fact that oil supply from the U.S., until that point the world's largest oil producer, had just gone past peak in 1970.[3] When the entire oil-producing world outside of OPEC passes it's peak, OPEC's market power will be magnified and the potential for higher and more volatile oil prices will increase.

3. RESOURCES, OPEC AND THE OIL TRANSITION

The astonishing rate at which the world is consuming petroleum must be placed in the context of how much oil remains to be produced. How much oil *is* left? More importantly, can it be produced at a rate that keeps pace with growing demand? While some believe that oil production will peak suddenly and soon, and then decline rapidly with disastrous consequences, the conventional wisdom now holds that oil production from non-OPEC regions will soon reach a plateau (or has done so already). Increased oil supply must then come either from OPEC or a large-scale transition to unconventional sources of liquid fuels must occur. This implies a magnification of the market power of the OPEC cartel that is likely to have important implications for the future costs of transport fuels.

3.1 Conventional oil resources

A comprehensive, scientific survey of world conventional petroleum resources 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 described by 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.

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

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[3] While U.S. crude oil production peaked in 1970, U.S. total petroleum production including natural gas plant liquids actually peaked in 1972, the year before the first oil price shock.

we run out of oil?" but rather "When will we no longer be able to increase its rate of 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.

When will world 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 exists? (see Table 1).
2. How much oil does OPEC have 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 will conventional oil production decline once the peak has been reached?

Table 1. **USGS 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.

The Association for the Study of Peak Oil (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 4). 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 as a result of extremely high oil prices.
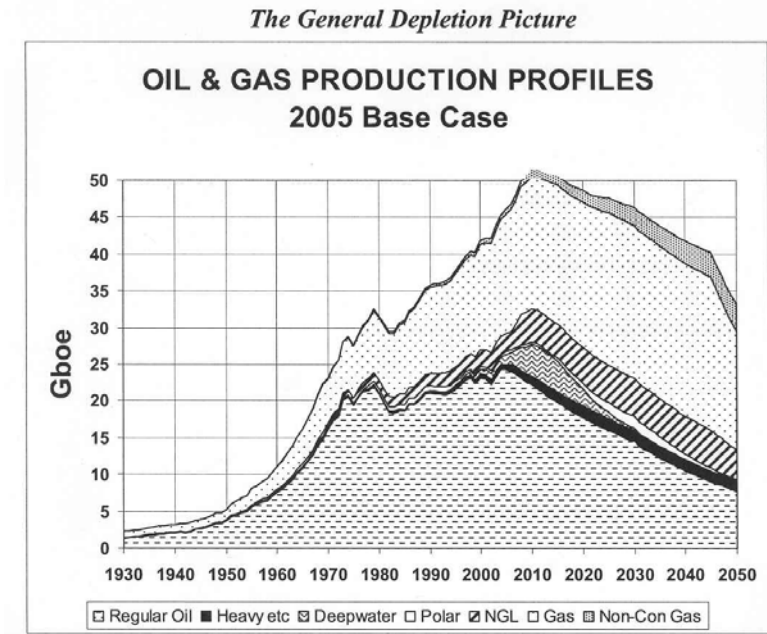

Figure 4. **ASPO Estimates of Global Oil and Gas Production to 2050**

(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.

> "The concept of peak oil production and its timing are emotive subjects which raise intense debate. Much rests on the definition of which segment of global oil production is deemed to be at or approaching peak. Certainly our forecast suggests that the non-OPEC, conventional crude component of global production appears, for now, to have reached an effective plateau, rather than a peak. Having attained 40 mb/d back in 2003, conventional crude supply has remained unchanged since and could do so through 2012. While significant increases are expected from the FSU, Brazil and sub-Saharan Africa, these are only sufficient to offset declines in crude

supply elsewhere. Put another way, all of the growth in non-OPEC supply over 2007-2012 comes from gas liquids, extra-heavy oil, biofuels (and, by 2012, 145 kb/d of coal-to-liquids from China)." (IEA, 2007, p. 30)

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 four 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 4). 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).
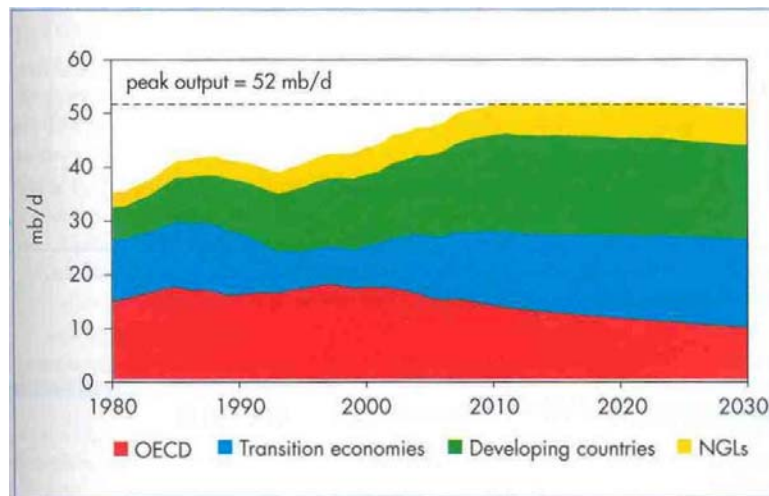

Figure 5. **Non-OPEC Crude Oil and NGLs Production, World Energy Outlook 2006**

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 6). Like earlier 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.
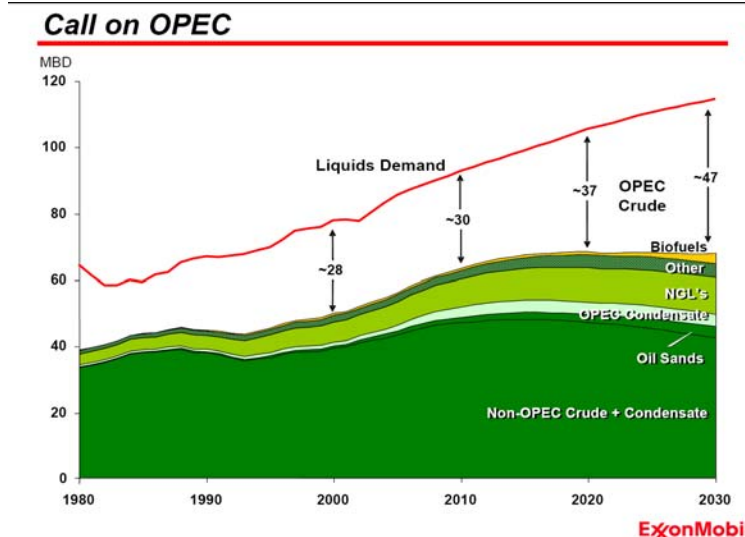

Figure 6. **ExxonMobil Projections of World Petroleum Supply to 2030**
(Tillerson, 2004)

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.

The EIA's Reference, Low World Oil Price and High World Oil Price cases are defined by differing views about, 1) the size of conventional oil resources (ultimately recoverable) and 2) the willingness of OPEC members to expand production (EIA, 2007, p. 34). The Reference case is based on the U.S. Geological Survey's mean estimates of oil and natural gas resources (Ahlbrandt et al., 2005). The High Oil Price case assumes a 15% smaller crude oil resource while the Low Oil Price case assumes that world oil resources are 15% larger. These assumptions affect the degree to which non-OPEC supply can increase in the three cases. Note that unlike the ExxonMobil and IEA projections of non-OPEC supply, the EIA's projections foresee increased non-OPEC supply throughout the forecast period, but these numbers include unconventional sources such as oil sands, extra-heavy oil, CTL and biomass-to-liquids (table 2). In the High Oil Price case, OPEC

decreases output through 2015, then increases it very gradually through 2030. In the Reference case OPEC output expands from 34 mb/d to 47.6 mb.d by 2030 and in the Low Oil Price case OPEC output reaches 54.7 mb/d in 2030.

Table 2. **OPEC and non-OPEC oil production in three AEO 2007 oil price cases (mb/d)**

	Low Price	Reference	High Price
OPEC			
2005	34.0	34.0	34.0
2010	34.7	34.7	31.2
2015	39.3	37.5	29.1
2020	43.9	40.2	29.3
2025	49.2	43.7	31.4
2030	54.7	47.7	33.3
Non-OPEC			
2005	50.3	50.3	50.3
2010	57.5	56.3	55.6
2015	62.1	60.2	60.9
2020	66.2	63.1	64.1
2025	70.1	66.3	66.0
2030	73.4	69.7	68.3

In terms of a realistic view of future world oil market evolution, these price scenarios have two problems. First, as Gately (2004) and the EIA itself (EIA, 2006) have demonstrated, the OPEC cartel can increase its oil revenues by producing less oil. As Figure 7 illustrates, cumulative oil production of 172 billion barrels through 2025 produces an estimated $7.1 trillion in oil revenues while producing 63 billion barrels more oil brings in $0.5 trillion less revenue. Countries whose economy is based on oil revenues will have no difficulty deciding which option is best for them. Second, all three oil price cases assume smooth evolution of OPEC output and world oil prices. As noted above, this is because the projections are intended as descriptions of central tendency rather than predictions of future price paths. Nonetheless, this is a complete break with the history of the world oil market since OPEC became a force in it (see, Figure 1). In the future, OPEC's market power is likely to increase rather than decline. As a consequence, future world oil prices are virtually certain to be volatile, as explained below.
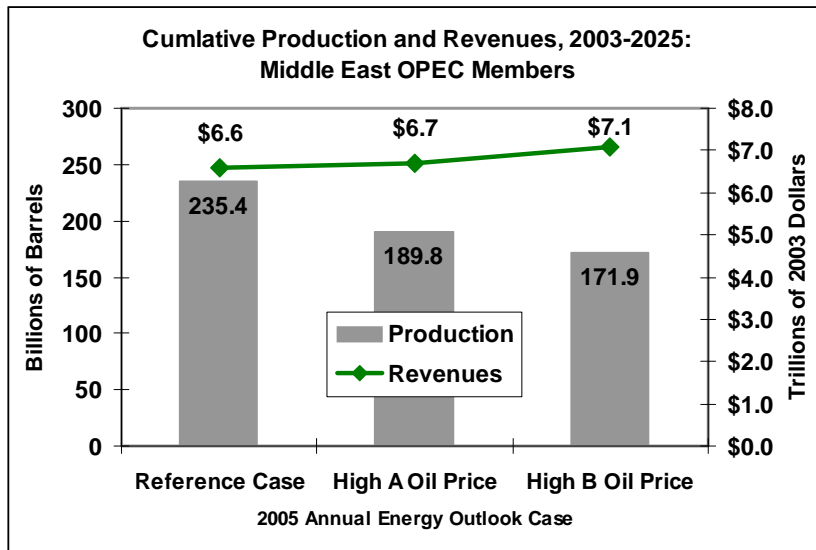
**Cumlative Production and Revenues, 2003-2025:
Middle East OPEC Members**

Figure 7. **OPEC Revenues at Alternative Production Levels, 2003-2025**.
(DOE/EIA, 2006)

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 and its Texas Railroad Commission was
reasonably successful in maintaining stable oil prices. But the peaking of U.S.
crude oil production at 9.64 mb/d in 1970 transferred market power to 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 makes both very likely.

3.2   Unconventional Fossil Hydrocarbon Resources and Coal

The path of least resistance will be to fill the growing gap between world
petroleum demand and conventional oil supply with conventional fuels derived
from unconventional fossil resources. The quantities of unconventional fossil
hydrocarbons from which transportation fuels can be made are enormous.
Because unconventional petroleum resources have generally been either
technologically or economically impractical in the recent past, 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 small
(relative to the world's consumption of crude oil) but increasing 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 2025 and 21.1 mb/d in 2030 in EIA's high world oil price case (Figure 8).

EIA IEO2006 Projections of World Conventional and Unconventional Petroluem Supply in 2030

Scenario	Conventional	Unconventional
Low Oil Price	120.6	7.1
Reference	106.5	11.5
High Oil Price	80.8	21.1

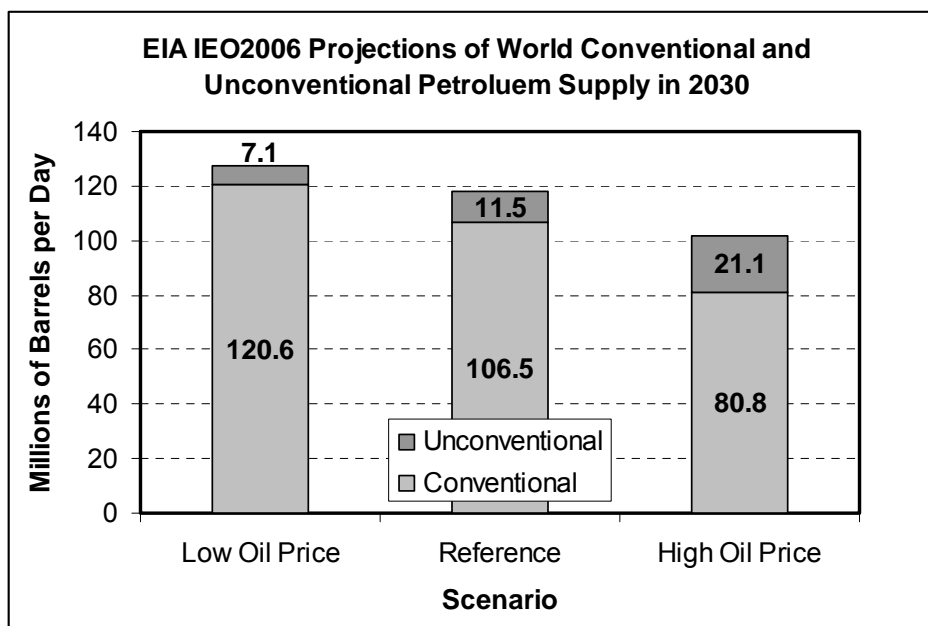*(Millions of Barrels per Day)*

Figure 8. **EIA IEO 2006 Projections of World Conventional and Unconventional Petroleum Supply in 2030**

Conventional transportation fuels can also 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).

3.3   OPEC market power and world oil prices

Static or declining conventional oil supplies from non-OPEC oil producers will magnify the OPEC cartel's market power with important implications for the level and stability of oil prices and the costs of transport fuels. Greater OPEC market power is likely to lead not only to higher oil prices on average but to increased volatility, as well. This too is unfortunate because price volatility increases the risk for energy companies contemplating the large capital investments that will be needed to satisfy the world's growing demand for transport fuel.

Greater OPEC market power is likely to increase price volatility because of the order of magnitude difference between the short-run and long-run responsiveness of world oil demand and non-OPEC oil supply to oil price, and because OPEC is not a single-minded monopolist but a cartel of sovereign states with differing agendas. Economic theory shows that the market power of a monopolist who controls part but not all of the market increases as: 1) its market share increases, 2) the price elasticity of demand decreases and, 3) the price elasticity of supply of its competitors decreases. In addition (as shown in the appendix), this market power is magnified when demand is growing and rest-of-world supply declines. Market power is equivalent to the ability to increase revenues by decreasing output. The profit-maximizing price of the partial monopolist therefore depends on its market share, and the price elasticities of demand and rest-of-world supply it faces. Because these elasticities are ten times smaller in the short-run (~ 1 year) than in the long-run (~ 15 years), the price that maximizes OPEC's profits in the short run is far higher than it can sustain in the long run.[4]

Using the static equations for profit-maximizing price presented in the appendix to this report, OPEC's short-run (upper curve) and long-run (lower curve) profit maximizing price curves have been constructed as a function of

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[4] Moreover, long-run price elasticity will be affected by technological change and is therefore always uncertain.

its market share (Figure 9). The curves are shown as error bars rather than lines to reflect the fact that supply and demand elasticities are not known with absolute precision. On the same graph, historical world oil prices have been plotted against OPEC's market share at the time. The pattern is revealing. From 1965 to 1972, as OPEC members were nationalizing their oil resources and the United States was still the world's largest oil producer, prices were below even the long-run profit maximizing level for the cartel. When the Arab members of OPEC boycotted the nations that aided Israel in the 1973 October War, world oil prices shot up above the long-run profit maximizing level (but were still well below the short-run profit-maximizing level). Prior to that year world oil demand had been increasing at nearly 7% per year. For the next five years OPEC was able to sustain prices well above the long-run level with only a modest loss of market share. The loss of oil supply during the Iraq-Iran War caused another doubling of world oil prices, this time to the level of the short-run profit maximizing price curve. At this point OPEC elected to defend the higher price of oil. However, the cartel's only weapon is to further reduce oil production. But cutting back on production means sacrificing market share and loss of market share means loss of market power. Over this period Saudi Arabia sacrificed the most, reducing its oil output from 9.9 mb/d in 1980 all the way to 3.4 mb/d in 1985 (EIA, 2007, table 11.5). At that point there was no ammunition left and OPEC was forced to surrender to market forces. Prices crashed in 1986. But with three fourths of the world's proven oil reserves and more than half of its ultimately recoverable resources of conventional oil, OPEC's regaining market share in a growing world oil market was only a matter of time (Greene, Jones and Leiby, 1998). With market share came the rebirth of market power. And when OPEC's market share crossed 40% again in 2004, the price of oil rose sharply.
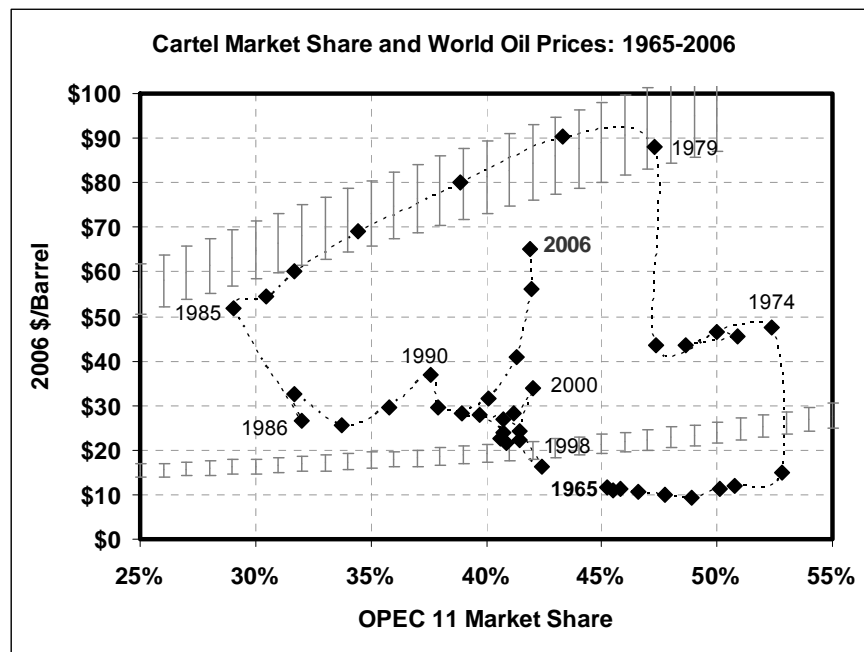

Figure 9. **History of World oil Prices Since 1965 in the Context of OPEC's Long- and Short-run Profit-Maximizing Monopoly Price Functions**.

Dependence on petroleum creates enormous economic costs for oil consuming states. Greene and Ahmad (2005) estimated the total economic costs of oil dependence to the U.S. economy since 1970 at over $4 trillion. Leiby (2007) estimated the external economic costs to the OECD countries of oil dependence at approximately $40 per barrel. Neither study attempted to count the diplomatic and military costs of conflicts over oil but they are clearly substantial. In his recently published memoir, Alan Greenspan (Paterson, 2007), former chief of the U.S. Federal Reserve Board stated flatly that that the ongoing war in Iraq was, "…all about oil." While there is some uncertainty about the sense in which he intended that statement to be interpreted, there can be no doubt that there would have been no war if there were no oil in Iraq or its surrounding region, or if the world had ample, economical substitutes for oil. The Iraq war is estimated to have already cost more than half a million lives (Burnham et al., 2006) and many more injured and displaced. The cost to the Iraqi and U.S. economies will certainly be numbered in trillions of dollars. Despite the difficulties of attribution and quantification, the potential for future costly conflicts over oil must not be ignored in any assessment of the future costs of transport fuels.

4. POLICY & TECHNOLOGICAL CHANGE

In addition to the forces of supply and demand discussed above, technological change, especially technological change driven by strong policies to protect the global climate and secure sustainable energy sources for global transport could have the greatest impact not only on the future prices of transport fuels but on the kinds of energy used to perform the work of moving people and commodities. Today, alternative energy sources cannot compete with conventional and unconventional sources of liquid hydrocarbon fuels on the scale necessary to do the transportation work of the global economy. Biomass derived fuels can make an important but limited contribution. Energy efficiency improvements based on proven technologies can play a critical role by limiting the growth of transport energy demand. However, the past thirty years of experience have shown that technologies that can increase motor vehicle fuel economy will, in the absence of policy constraints, instead be used to provide greater power and weight. New energy carriers like hydrogen or electricity show enormous promise but will need significant technical breakthroughs and strong policy commitments if they are to displace conventional hydrocarbon fuels. The potential for a revolutionary transformation in transport energy use is real, however, and just as it cannot be counted upon it cannot be dismissed.

4.1   Carbon sequestration

The price of carbon will likely be a component of all future liquid hydrocarbon transport fuels. If carbon prices are in the range of $50-$100 per ton of CO_2, transport fuel prices will increase by $0.15-$0.25 per liter. However, if carbon-

intensive unconventional fossil resources such as coal-to-liquids or oil shale become the marginal source of supply for transport fuels, then the cost of carbon capture and storage will become an important element of the market price of oil. Fortunately, gasification followed by Fischer-Tropsch synthesis generates a relatively pure stream of CO_2 emissions, unlike electricity generation plants. This is an important advantage because capture is believed to be the largest component of CCS cost. Capture costs from F-T synthesis are likely to be in the range of $5-$10/tCO2, at the lowest end of the range of capture cost estimates (IPCC, 2005). Transport adds $1-$8/ton, depending primarily on the distance to a suitable storage site, which geologic storage will probably add another $0.50-$8/ton, and monitoring and verification $0.10-$0.30. This would imply very approximately $10-$25/tCO_2 , or less than $0.10/liter, even at the high end of the range. Thus, assuming feasible CCS, the cost of coal-to-liquids transport fuels may be on the order of $0.25-$0.35/liter higher due to restrictions on carbon emissions.

The feasibility of carbon sequestration is by no means certain. Risks range from gradual leakage from geologic formations to catastrophic failures of pipelines. Legal and regulatory issues remain to be resolved, such as subsurface property rights and liability for CO_2 leakage. If CCS is not feasible for transport fuels, the cost of coal-to-liquid fuels with double the well-to-wheel carbon emissions of conventional gasoline, could include an additional $0.30-$0.50/liter in carbon charges, or $45-$80 per barrel of CTL fuel. The cost differential between CTL and conventional petroleum would therefore be on the order of $0.05-$0.10/liter ($8-$16 per barrel) with successful CCS or $40-$55 per barrel without it. If carbon-intensive unconventional fossil resources are the marginal source of supply for transport fuels, prices will be higher by something like $10-$50 per barrel, and if there is uncertainty about the costs and feasibility of CCS, potentially even more volatile.

4.2   Energy Efficiency

By reducing the rate of growth in demand for transport fuels energy efficiency improvement can put downward pressure on fuel prices and postpone investments in unconventional resources. At present, reduction of greenhouse gas emissions rather than petroleum consumption is the primary objective driving energy efficiency improvements to motor vehicles. The EU has set a voluntary target of 120 gCO_2/km for new passenger cars by 2012. In the U.S., California and other states have set a mandatory target of 128gCO_2/km for 2016. Japan and China have also established comparable fuel economy standards for light-duty vehicles (An et al., 2007). Relative to current new vehicle energy efficiencies, these standards represent reductions of from 20% to 33%. This appears to be approximately the limit of what can be achieved with proven technology and without changing the size or performance of light-duty vehicles.

The 2006 World Energy Outlook examined two alternatives to its reference scenario designed to reduce greenhouse gas emissions and petroleum consumption (IEA, 2006a). The Alternative Policy Scenario (APS) included

most policies under serious consideration but not yet implemented. For example, the U.S. was assumed to adopt California's greenhouse gas emissions standards for light-duty vehicles. The EU was assumed to meet its voluntary emissions goals, and the Japanese and Chinese weight-based standards were assumed to be met and strengthened. All of these standards are to be met before 2020, yet additional policies were not considered in the APS. Modest enhancements of existing biofuels initiatives were also assumed. These policies were estimated to achieve a reduction in transportation oil consumption of 7.6 mb/d and a reduction in transport's CO_2 emissions of 0.9 Mt, or 11%. A Beyond Alternative Policy Scenario (BAPS) assumed that the market share of hybrid vehicles would increase to 60% from 18% in the APS, and that the commercialization of cellulosic conversion technologies would enable a doubling of the APS biofuels goals. The result was an additional 7 mb/d of oil savings and 1 Gt of CO_2 in 2030.

Far more could be achieved with advanced technology almost certain to be production-ready before 2030 (IEA, 2006b, Tables 5.2 and 5.5). It has been estimated that by 2030, advanced light-duty vehicles with turbo-charged, direct-injection gasoline engines with variable valve timing and lift, variable compression ratios and cylinder cut out at light loads, combined with improved aerodynamics, lower rolling resistance tires, down-weighting via materials substitution and advanced manual-automatic or continuously variable transmissions, would consume approximately half as much fuel per kilometer as today's vehicles (Kasseris and Heywood, 2007). With further advances in battery technology and electric drive systems, the fuel economy of hybrid electric vehicles could be three times the current level by 2030 (Kromer & Heywood, 2007). Vehicles would need to be lighter by about 20%, and motorists would have to forego further *increases* in power. To have a major impact on transport energy use by 2030, the needed breakthroughs would have to be accomplished by 2015-2020 to allow time for new technologies to penetrate the global stock of motor vehicles.

To translate technical energy efficiency improvements described above into reductions in petroleum use and greenhouse gas emissions, consumers must be willing to forego further *increases* in vehicle power and mass. To achieve the 2030 potential for light-duty vehicles, consumers would have to accept reductions in vehicle mass, but not in vehicle size. Recent U.S. analyses of car size, weight and safety suggests that overall road safety would be *improved* if vehicle weights were reduced without reducing track width or wheelbase (Van Auken and Zellner, 2005; Ross, Patel and Wenzel, 2006) but the issue remains controversial (e.g. Kahane, 2003). A better understanding of this issue leading to public acceptance of weight reduction via material substitution seems essential to achieve the doubling and tripling of motor vehicle fuel economy envisioned by the engineering analyses cited above.

Of course, light-duty vehicles are not the only transportation mode that relies on liquid hydrocarbon fuels, although they are certainly the largest consumers. Hybrid technology is well suited to heavy trucks engaged in local pick-up and delivery operations and could improve energy efficiency by 25%-45% by 2030 (Duleep, 2007). Similar improvements are possible for long-haul trucks by

means of reduced aerodynamic and rolling resistances, reduction of auxiliary loads, reduced idling, reduced tare weight, and incremental engine and transmission improvements (Duleep, 2007). Recently, Japan has directly challenged the prevailing belief that the market for energy efficiency in commercial trucks operates efficiently by establishing the world's first heavy truck efficiency standards in 2006 (Wani, 2007). The standards require a 12% improvement in heavy truck and bus fuel economy by 2015. To date, targets for 2006 and 2007 have been met by truck manufacturers but the jury is still out on the overall efficacy of the standards. If the Japanese standards prove to be effective, regulating heavy truck fuel economy or greenhouse gas emissions could become a worldwide policy strategy for curbing oil use and greenhouse gas emissions.

4.3   Alternative Energy Sources

Global production of biofuels for transport amounted to only about 1% (0.8 EJ) of road transport fuel consumption in 2005 (Doornbosch & Steenblik, 2007). Perhaps as much as 20 EJ (11%) of ethanol and biodiesel could be produced by conventional methods by 2050. It is becoming clear, however, that without breakthroughs in methods of producing biofuels from ligno-cellulosic feedstocks, such a level of production would have serious impacts on food prices and cause significant environmental degradation. Alternatives to ethanol could be produced via biomass gasification and Fischer-Tropsch synthesis, however, this pathway faces serious logistical challenges with respect to feedstock supply at sufficient scale and regularity to be economical. Even given technological breakthroughs, the total potential for biofuels may be limited to 40-50 EJ per year and costs are likely to be in the vicinity of $60/bbl of oil equivalent (IEA, 2006b, p. 283). Thus, without some form of policy support, biofuels will have difficulty competing with conventional transport fuels from unconventional fossil resources.

Plug-in hybrid vehicles could substitute electricity from the grid for much of the energy requirements of passenger vehicles, but not without a breakthrough in battery technology permitting repeated deep discharges and a dramatic reduction in battery cost (IEA, 2006, p. 317). Similarly, hydrogen fuel cell vehicles need perhaps an order of magnitude reduction in cost for fuel cell stacks, as well as a breakthrough in on-board hydrogen storage. Looking forward, the task of displacing significant amounts of conventional fuels with hydrogen and electricity seems daunting. Looking backward at the past 20 years of progress in battery and fuel cell technology, on the other hand, it seems quite possible.

Technological change is certain. Whether it will go far enough and fast enough to change the energy basis of transport remains to be seen. In any event, without strong public policies neither major fuel economy improvements nor significant market shares for alternative energy sources seem likely.

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5. THE OUTLOOK FOR TRANSPORTATION ENERGY PRICES

Reference case forecasts of future oil prices foresee a period of declining or slightly rising prices through 2015, followed by gradually increasing prices through 2030 (Table 3). As measures of central tendency, these projections appear to reflect the likelihood that unconventional fossil resources will become the marginal sources of supply for transportation fuels, since it appears that even CTL can be produced at costs in the vicinity of $40-$50 per barrel (IEA, 2006b, p. 270).

The forecasts also may reflect the marginal cost of CTL-derived fuel in the presence of strong carbon constraints, if CCS is feasible. Given a carbon price on the order of $50/tCO$_2$, if CCS is feasible and the IPCC costs estimates are approximately correct, CCS would add about $10-$25 per barrel to the cost of CTL liquids. CTL liquids, however, are superior in quality to crude oil derived fuels and might command a premium on the order of $10 per barrel. The IEA and EIA reference oil price projections of $55-$59 per barrel are roughly consistent with such a scenario. However, if CCS is not feasible and CTL is the marginal source of supply, the additional fees for double the carbon emissions might imply that these estimates are $10 per barrel, or so, on the low side. In the world of 25-year oil price projections a difference of $10 per barrel is in the noise.
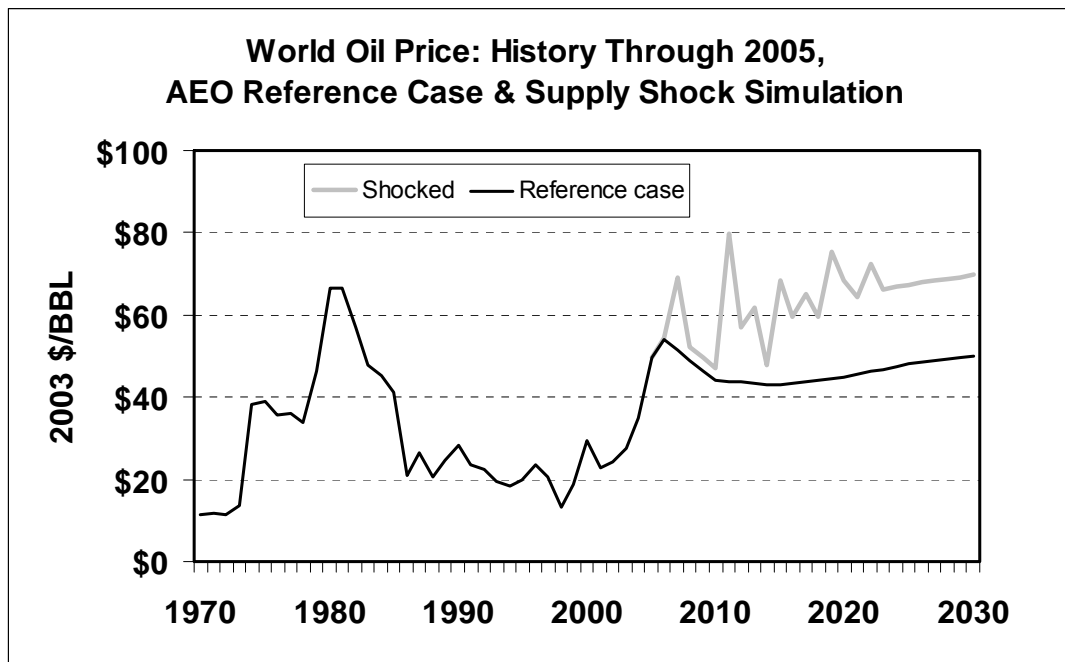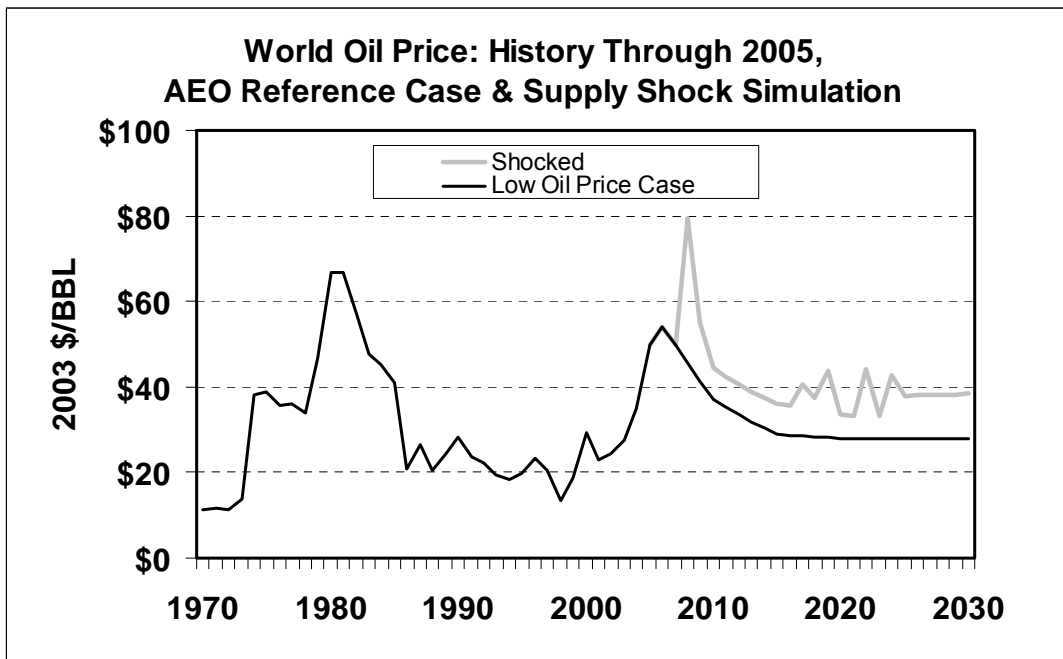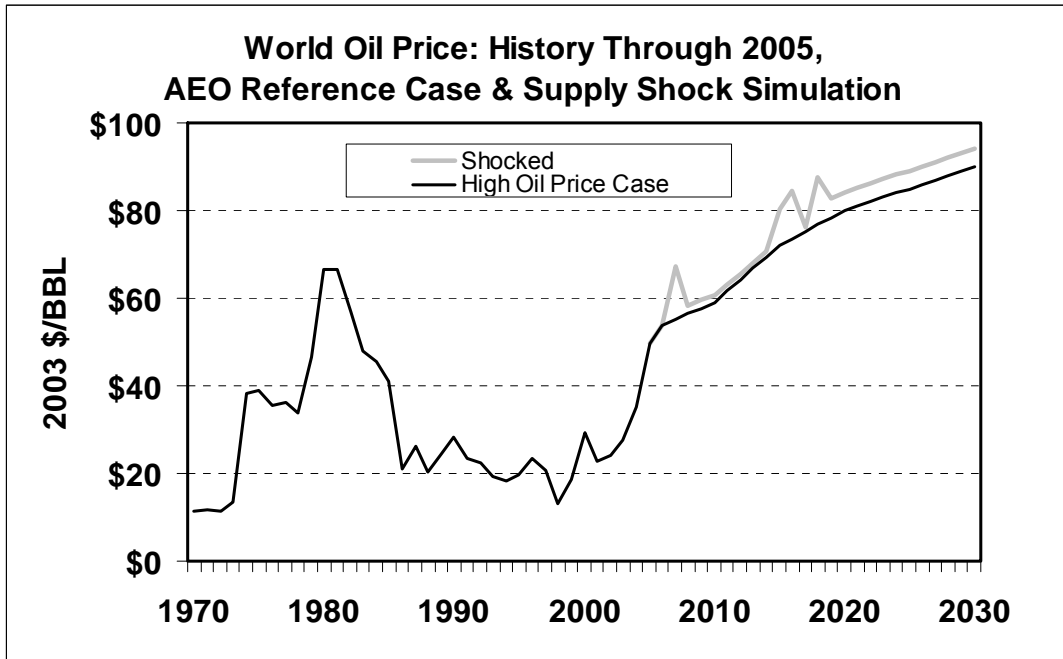
Table 3. **Projections of world oil prices, 2010-2030**

Projection	2010	2015	2020	2025	2030
IEA Reference	$52	$48	$50	$53	$55
AEO Reference	$57	$50	$52	$56	$59
AEO Low World Oil Price	$49	$34	$34	$35	$36
AEO High World Oil Price	$69	$80	$89	$94	$100
Global Insights, Inc.	$57	$47	$45	$43	$40
Energy & Environmental Analysis, Inc.	$57	$50	$47	$45	NA
Deutsche Bank AG	$40	$40	$40	$40	$40
Strategic Energy & Econ. Res., Inc.	$44	$45	$46	$46	$47
Energy Ventures Analysis, Inc.	$42	$42	$46	$49	NA

Source: EIA Annual Energy Outlook 2007, Table 19 (rounded to nearest dollar).

What is virtually certain is that future oil prices will not follow the smooth paths these measures of central tendency may seem to imply. OPEC's increasing market power will make future price volatility more likely. In addition, the risks energy companies face with respect to the massive investments they must make to increase liquid fuel supplies to meet growing world demand imply that the expansion of supply is not likely to be smooth and orderly.

It seems far more likely that future oil prices will evolve in patterns similar to those illustrated in Figures 10a-10c. The "shocked" cases shown in these three figures simulate the impacts on world oil prices of deviations from the projected OPEC oil supply. The OPEC supply deviations have been calibrated to be similar to actual differences from historical projections by the U.S. Energy Information Administration (Greene & Leiby, 2006). The three price cases shown in the three graphs reflect EIA's judgment about how differences in the quantity of conventional oil resources that actually exist and OPEC's willingness to expand production will affect the general trend of oil prices in the future. The graphs below are but a few of an infinite number of possible future price paths. In that sense, the probability that any one of them will be the true future price path is zero. They are shown simply to illustrate the strong likelihood that future transportation fuel prices will be volatile rather than regular, and that while prices may be higher than in the past, they may also at times be much lower than they are today.

World Oil Price: History Through 2005, AEO Reference Case & Supply Shock Simulation

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World Oil Price: History Through 2005, AEO Reference Case & Supply Shock Simulation

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Appendix.
Demand Growth, Oil Peaking and OPEC Market Power

Growing demand for oil or shrinking supply capability from competitive oil producers magnifies the market power of the partial monopolist. Assume that oil demand is growing exogenously at a rate of r×100% per year and, in addition, that rest-of-world supply is exogenously shrinking at δ×100% per year. Shrinking supply may be a more controversial assumption than growing demand which has been observed throughout the world as economies expand. Shrinking supply might occur as a result of the peaking of conventional oil production, if alternative unconventional sources of liquid fuels cannot be brought on line quickly enough. In any case, the derivation presented below is equally valid for the special case where δ=0.

Once again, the partially monopolistic cartel is assumed to maximize its profit, Π, which is a function of the market price, $P(q, Q_o)$, which depends on the supply from the cartel, Q_o, as well as the supply from the competitive producers, q. For convenience, it is assumed that the marginal cost of production for the cartel is constant at C. With exogenously growing demand and shrinking supply the cartel's profit function is the following.

$$\Pi(Q_o) = P(qe^{-\delta t} + Q_o)Q_o - CQ_o = P(Qe^{rt})Q_o - CQ_o$$

The first order condition for maximizing profit is obtained by differentiating with respect to Q_o.

$$\frac{\partial \Pi}{\partial Q_o} = \frac{\partial P}{\partial Q}\frac{\partial Q}{\partial Q_o}Q_o + P - C = e^{rt}\frac{\partial P}{\partial Q}\left[e^{-\delta t}\frac{\partial q}{\partial Q_o} + 1\right]Q_o + P - C = 0$$

Dividing through by P, multiplying the first term on the right-hand side by Q/Q and rearranging terms gives the partial monopolist's profit maximizing pricing rule in a dynamic market.

$$e^{rt}\frac{\partial P}{\partial Q}\frac{Q}{P}\frac{Q_o}{Q}\left[e^{-\delta t}\frac{\partial q}{\partial Q_o} + 1\right] + 1 = \frac{C}{P}$$

$$P = \frac{C}{1 + e^{rt}\frac{1}{\beta}\sigma\left[e^{-\delta t}\frac{\partial q}{\partial Q_o} + 1\right]}$$

From the profit maximizing price equation it is clear that a growing market demand effectively multiplies the market share of the cartel. A shrinking ROW supply also magnifies the market power of the cartel, since $\partial q/\partial Q_o < 0$ and thus $0 < e^{-\delta t} < 1$ will cause the term in square brackets to increase.

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A growing market demand or a shrinking ROW supply has another, possibly more important implication. Whereas in a static market the only way for the monopolist to cause price to rise is to cut production, in a growing market all the is needed for price to increase is to not expand production. This could be a critically important determinant of the cartel's ability to achieve cooperation among its members. Undoubtedly it is easier to persuade members not to expand output than to agree to and carry out production cuts.