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OIL DEPENDENCE: IS TRANSPORT RUNNING OUT OF AFFORDABLE FUEL?

TRANSPORT RESEARCH CENTRE

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TRANSPORT RESEARCH CENTRE

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The International Transport Forum is an inter-governmental body within the OECD family. The Forum is a global platform for transport policy makers and stakeholders. Its objective is to serve political leaders and a larger public in developing a better understanding of the role of transport in economic growth and the role of transport policy in addressing the social and environmental dimensions of sustainable development. The Forum organises a Conference for Ministers and leading figures from civil society each May in Leipzig, Germany.

The International Transport Forum was created under a Declaration issued by the Council of Ministers of the ECMT (European Conference of Ministers of Transport) at its Ministerial Session in May 2006 under the legal authority of the Protocol of the ECMT, signed in Brussels on 17 October 1953, and legal instruments of the OECD. The Forum's Secretariat is located in Paris.

The members of the Forum are: Albania, Armenia, Australia, Austria, Azerbaijan, Belarus, Belgium, Bosnia-Herzegovina, Bulgaria, Canada, Croatia, the Czech Republic, Denmark, Estonia, Finland, France, FYROM, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Mexico, Moldova, Montenegro, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, the United Kingdom and the United States.

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Further information about the International Transport Forum is available on Internet at the following address:
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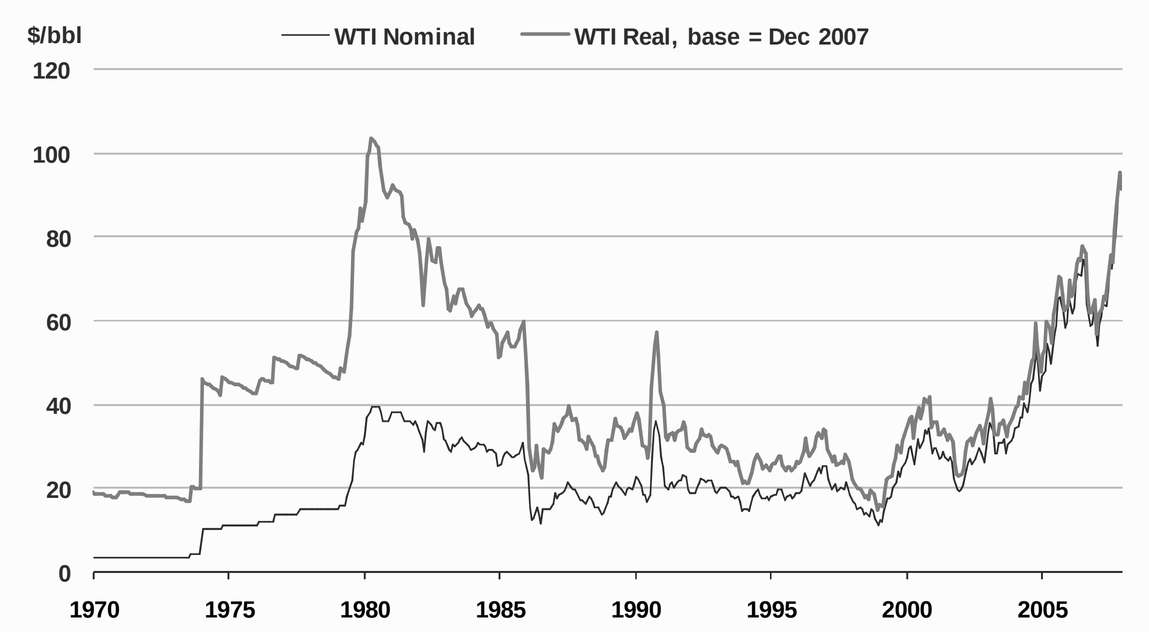
EXECUTIVE SUMMARY

The transport sector’s demand for oil is less price sensitive than any other part of the economy. This is partly because demand for transport services is relatively insensitive to price and partly because substitutes for oil in road transport are currently far from cost-effective. Evidence from the USA suggests that as incomes rise, transport sector oil demand becomes even less price sensitive. This implies that oil consumption is set to become increasingly concentrated in the transport sector. It also implies that relatively limited fluctuations in demand can have increasingly significant effects on oil prices.

Figure 1. **Spot crude oil price 1970-2007: real and nominal prices**



Notes: Price sources: Dow Jones for pre-Jan 1985 data, Platts monthly Cushing spot west Texas intermediate (WTI) crude from Jan 1985; Deflated taking December 2007 baseline and using monthly OECD consumer price index data.

Source: IEA.

Oil prices approached their historical 1980 peak in real terms in November 2007, when the Round Table convened (see Figure 1). Because of growth in incomes since 1980 and the reduced oil dependence of OECD economies, the economic impact of high prices has been weaker than during earlier oil price peaks. Moreover, the current high prices are a result of strong economic growth rather than a supply shock as was the case in the oil crises of the 1970s. Nevertheless, the transport sector is the most exposed part of the economy to oil prices.

OPEC market power is expected to increase. OPEC, and particularly the Middle East, will see its share world oil supply increase because production of conventional oil from other parts of the world has either peaked and entered a phase of permanent decline or reached a plateau for the foreseeable future. OPEC will therefore be in a strong position to defend high prices against a background of rising demand, particularly from the emerging economies.

That is not to say prices will inevitably rise further or even stay at current levels. They could also fall substantially if economic growth weakens, particularly in the increasingly interdependent US and Chinese economies. Price instability is likely to persist. This creates uncertainties that delay major investments in new oil production and refining capacity, as well as in fuel efficient car technology.

In the longer term, non-conventional oil resources could supply a large part of oil demand at prices from around $40 a barrel. The conventional view is that reserves of tar sands, oil shale and coal are sufficient to provide for decades of further growth in oil consumption, but this was challenged by some Round Table participants who believe coal supply has already peaked. As non-conventional oil sources become more critical to world oil supply, a better understanding of their availability and the economics of production is increasingly important.

Policy responses to growing OPEC market power can seek to either promote non-conventional oil production in non-OPEC countries or reduce oil consumption. Policies to promote alternative fuels are also relevant but of limited short term potential as discussed in the conclusions of the JTRC Round Table on Biofuels: Linking Support to Performance (OECD/ITF 2007). Non-conventional sources of oil are associated with more than twice the emissions of greenhouse gasses from conventional oil. Their development may therefore be constrained by climate policy.

Intervention to internalize the costs of CO_2 emissions from transport serves to both mitigate climate change and reduce oil consumption at the same time. Carbon taxes are the preferred instrument of many economists to achieve this because they provide incentives for attainment of the environmental target at least-cost. However, vehicle fuel efficiency or CO_2 emissions standards have some advantages, not least in terms of political acceptability. They are also able to correct the difference between social and private discount rates at the point of vehicle purchase. Differences between social and private discount rates, and imperfections in consumers' decisions on what fuel economy to buy, may justify standards even if taxes reflect external costs.

Standards are vulnerable to being undermined by the rebound effect – i.e. the cost savings resulting from increased fuel efficiency may be taken up by additional driving or upgrading of the power or weight of the vehicles purchased. There is considerable agreement that the rebound effect in terms of increased driving is small (around 20%, maybe smaller[1]), so that standards do translate into substantial reductions in fuel consumption. To the extent that the rebound effect is a problem, it indicates a failure to price CO_2 emissions and other transport externalities correctly. This suggests that if a standard is the primary tool adopted for reducing transport sector CO_2 emissions a secondary tax element is required – ideally in the form of a carbon tax or alternatively through fuel taxes or differentiation of taxes on vehicle purchase or ownership. It also increases the urgency of introducing tools to manage congestion.

Transport, environment and oil security policies interact in a number of ways and there are trade-offs beyond the environmental impacts of developing non-conventional oil. Dieselisation of the car fleet, initially triggered by relatively low taxes on diesel fuels, has been the cornerstone of progress in

Europe to reduce CO_2 emissions from the transport sector. As a consequence, the market share of diesel has grown strongly and has reached almost 70% of road transport fuels in the EU. But there are limits to the degree to which the refining process can switch production from one type of fuel to another without consuming large additional amounts of energy to convert oil products. The excess diesel demand in Europe is currently met through trade, with diesel imported from Russia and the USA and gasoline exported from Europe to America. If any other major car market were to follow the dieselization path, diesel prices would rise sharply and CO_2 emissions would increase.

Two important issues arise when the energy security and greenhouse gas emissions from transport are viewed from a broader perspective. First, there is the question of how to distribute greenhouse gas abatement efforts among different sectors. Cost-effective CO_2 abatement strategies should aim to distribute efforts over sectors efficiently. The challenge is to minimize simultaneously CO_2 abatement costs, potential losses in the competitiveness of industry and the costs of energy import dependence. In this sense, the large share of transport in total CO_2 emissions in itself provides little guidance on how large this sector's contribution should be, although it needs to be recognised that the political process very likely will request a substantial contribution from transport to cutting overall emissions.

Second, intervention to reduce greenhouse gas emissions from the transport sector needs to be integrated with policies to reduce the other external costs of transport – local air pollutants, accidents and especially congestion. Congestion costs greatly outweigh the cost of CO_2 emissions from transport according to most studies. The large impact on CO_2 emissions (-20%) of congestion charges in London and Stockholm suggests that congestion management can facilitate the attainment of CO_2 reduction targets in congested areas.

1. INTRODUCTION

Crude oil prices were nearly 100 dollars a barrel when the Round Table convened in November 2007. In real dollar values, this matched the historic peak in oil prices of 1980 (Figure 1). The gradual rise in oil prices to these levels over the last five years was driven fundamentally by growing demand, especially from China, in combination with limited elasticities of supply. Whilst the outlook for supply and demand suggests prices are likely to remain high in the next five years, any slowdown in world trade and economic growth would result in a fall in oil prices, and probably a large fall. Whether prices rise or fall, they are expected to continue to be characterized by sharp spikes and troughs.

The Round Table examined the factors that drive oil prices and those likely to be most important over the next 25 years. It then reviewed recent evidence on the response of road transport activity to changes in fuel prices in order to explore linkages between transport and energy policies. The Round Table also examined the outlook for oil supply, together with the implications for climate policy if very heavy crude oils, tar sands, oil shales or coal-to-liquid fuels are developed on a large scale. Discussions then turned to potential policy responses, on the supply side and on the demand side, revealing some critical trade-offs between climate change and oil security policies. If these interactions are ignored, energy policies in the transport sector could result in large unnecessary costs.

2. OIL PRICES DRIVERS 1960 TO 2007

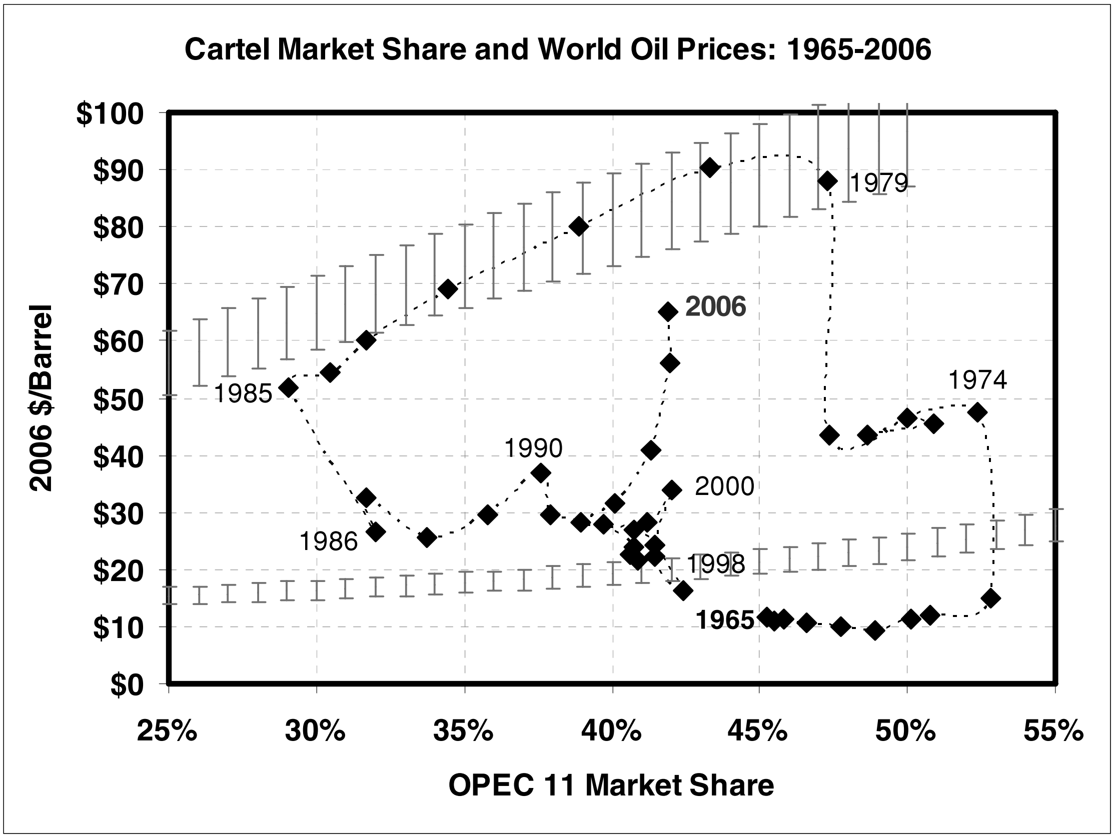
The impact on oil prices of action by the Organization of Petroleum Exporting Countries (OPEC) to restrict oil supplies in 1973 and 1979 is obvious in Figure 1. The motivation for restricting supply was in both cases political (the Yom Kippur War and the Iranian revolution) rather than aimed at maximizing profits[2] but coincided with peaking of US oil production, which endowed OPEC with market power to control prices. OPEC subsequently used this power to defend high oil prices by setting production quotas for its members. Although oil producers in the USA were unable to expand supply, the high prices did drive exploration and rapid development of oil fields in other non-OPEC countries. This gradually eroded OPEC market power until the point in 1985/6 when prices collapsed.

This price collapse stranded high-cost investments made by the major oil companies. The effects are still felt today, with a strong aversion to (over-) investing in oil production, oil refining and fuel efficiency on the part of private oil companies and car manufacturers. The consequence is that supply is not very elastic, even with strongly rising demand. And uncertainty over future prices, as well as rising resource costs for extraction and refining, further discourages major investments.

Even during periods of market dominance, OPEC decisions on production targets have sometimes resulted in sharp falls in prices, underlining the uncertainties in the market. The net effect is to increase upward pressure on oil prices.

David Greene traces these developments in price and market power in his report for the Round Table (Greene, 2007), summarized in Figure 2. The graph plots upper and lower bounds for oil prices, assuming OPEC seeks to maximize profit, as a function of short and long run oil price elasticities and as a function of conditions of supply outside OPEC. The maximum price band is calculated on the basis of short-run price elasticities for oil demand, i.e. the potential for rapid oil substitution and demand reduction in response to price increases, and short run elasticities for oil supply from the rest of the world. The lower band is based on the larger, long-run elasticities of demand and supply. These account for changes that take time to affect the market, such as the introduction of more fuel efficient vehicles or oil substitution in other industries.

Figure 2. **World oil prices since 1965 in the context of OPEC's long- and short-run profit-maximizing price functions**



Source: Greene 2007.

It should be underlined that the upper limit band is rather wide because short-run supply and demand elasticities are not easily calculated. It should also be noted that the band indicates a range for price trends and not an absolute limit. In particular, given that the underlying model is deterministic, prices can substantially overshoot these bounds for short periods.

Nevertheless, Figure 2 suggests a strong positive relation between OPEC market power and prices. Plotting historical prices on this framework reveals that until 1973 oil prices were below the lower bound. In 1979, OPEC raised prices to the level of the upper band and had sufficient market power to defend prices in this band through 1985. The cartel was able to increase profits by cutting output until a point where their market share fell below 30% of world oil supply. At this point longer term demand and supply responses started to be felt, discipline broke down in the cartel, production quotas were exceeded and the oil price collapsed, falling close to the lower bound of the model. OPEC nevertheless continued to control the bulk of low-cost oil production capacity and gradually recovered market share.

What does the analysis tell us about more recent history and about the near future? Production of conventional oil in non-OPEC countries is not expected to expand rapidly in response to current high oil prices. Some analysts foresee continuous decline and most expect a prolonged plateau in overall production levels. Extraction rates from existing oil fields cannot be accelerated beyond the limits imposed by the physical characteristics of each reservoir and the development of new sources is uncertain and slow. The bottom line is that in the near future the Middle East is expected to produce a rising share of world oil supply, which will tend to increase OPEC's market power.

In terms of Figure 2, current oil prices and OPEC market share are close to conditions that prevailed in the second oil shock. With a tendency for both oil demand and the cartel's market share to increase, OPEC is likely to be able to defend prices and maintain large economic rents for several years, until longer term responses begin to be felt.

3. OIL PRICE VOLATILITY AND CYCLICAL EFFECTS

In addition to the overall supply and demand balance and OPEC production rates, a large number of other factors can have a significant influence crude oil and oil product prices in the short term. On the supply side these include wars, political unrest, strikes, storms and hurricanes, accidents and unexpected maintenance. Refining is vulnerable to a similar set of problems. Crude oil and oil product stocks provide a buffer between supply and demand but stock changes can also have a strong influence on prices. On the demand side the most significant factors are colder or milder than average winter heating periods and economic downturns. Both crude and products are traded on international exchanges that have developed forward contracts to manage the price risks. Interaction between contract, spot and forward markets, between crude and product markets and between different types of trader increases the complexity of price behaviour.

At the time the Round Table took place crude oil prices on the spot market were higher than on futures markets. This had been the situation for some weeks, with forward prices falling the further into the future the date for settlement, despite a general expectation that oil supplies would remain tight. With this configuration of prices[3] there is pressure for traders to sell on the spot market and buy on the futures market until prices even out. However, the gains to be made this way have to be assessed against supply security, oil quality and timing of delivery risks. Refiners, which are an important part of the market, can only sell part of their inventory as they need to hold stocks for refining. The size of the gap between spot and futures prices is sometimes taken as a measure of the tightness of supply, but the situation is unstable and eventually there is a readjustment of prices, often a sharp fall in spot prices.

Although oil product prices are dependent on the price of crude oil they are also subject to trading pressures of their own. At the time of the Round Table oil refiners and distributors held sufficient stocks of products that competition between them to supply the end user markets coupled with a fear that further price increases would suppress demand prevented them fully passing on increases in the cost of crude oil to consumers. This ended a five-year run of unusually high refining margins, and is now expected to squeeze investment in new refining capacity.

Cuts in refinery investment will affect the supply and price of products in the future. This lagged effect is characteristic of both refining and crude oil production, driving cycles of over and under supply. Cycles initiated by the oil crises of the 1970s and the subsequent oil price collapse of 1985-86 continue to have an influence on markets today.

4. THE SHORT RUN OIL PRICE OUTLOOK

There are a very large number of factors that drive oil prices in the short term, but their impact depends ultimately on the fundamental balance between supply and demand. Sustained expansion of global economic activity is the underlying reason oil prices have risen to current levels, with consequent demand for oil expanding ahead of supply. Continued strong demand, particularly from China, is expected to maintain these oil market conditions for some time. China's economy is vulnerable, however, to any slowdown in demand for its exports. The difficulties in financial markets that began with the sub-prime mortgage crisis in the USA in 2007 illustrates the downside risks; China's industry Minister has warned of the potential for a sharp downturn in Chinese output as a result. (Financial Times, 16 October 2007).

Above ground constraints currently play a greater role in determining oil supply and prices than the long term dynamics of oil reserves, exploration and production. The most important is cost escalation in the oil services industry (drilling, oilfield development and pipeline construction) due to shortages of skilled labour and increases in the costs of raw materials.

Social and political tensions have depressed production in a number of regions, notably Nigeria and Venezuela, and war in Iraq has taken a large part of that country's potential output out of commission. In the medium term, output from these regions is expected to be restored, albeit under arrangements that allow for profit maximizing under OPEC coordination. More generally, it was noted that oil production concession agreements that provide lower rents (after adjusting for production costs) than in OPEC and other countries are inherently unstable, leading to renegotiation and eventually adjustment of the agreements.

Changes in the taxation of oil field development and production also have an impact. This concerns not only renegotiation of concession conditions in countries like Venezuela but also OECD countries where, for example, tax changes in the UK sector of the North Sea have depressed exploration and development activity.

The refining investment cycle mentioned already above could also affect prices for transport fuels over the coming five years. The oil majors lost large amounts of money in refining in the period 1996 to 2003 and as a result cut investment. The consequence was a shortage of capacity in the period 2004 to 2007 that helped drive up prices. New capacity is now coming on stream, particularly in the Middle East and India. More generally there has been investment in converting heavy fuel oil into diesel and other higher value products. This could result in over-supply of the market and falling prices in the medium term, although opinions are divided as to how likely this is.

5. LONG TERM OIL SUPPLY OUTLOOK

Kjell Aleklett's paper for the Round Table examines the production history of oil fields around the world stressing the inevitable eventual decline in output from all fields. Aleklett's paper also makes the important point that there are physical limits to the rate at which petroleum can be extracted from oil fields, determined by the characteristics of the reservoir and the oil. This limits the rate at which extraction from fields already in production can be increased in response to increasing demand or in response to supply disruptions. Based on work at Uppsala and Reading Universities, which models oil field development field by field around the world, the paper suggests non-OPEC production is already in irreversible decline and that the peak in production of conventional oil globally will arrive in only a few years, with an irreversible decline setting in thereafter.

This contrasts to analyses by the US Energy Information Administration (EIA) and the International Energy Agency (IEA), which foresee a prolonged plateau in non-OPEC production levels and do not rule out increases in production from new fields nor as a result of technological innovation. With strong growth in oil demand, either a decline or a plateau in non-OPEC production indicates increasing market power for OPEC in the future.

Views on potential production in the Middle East diverge sharply, largely because data on reserves in the region are poor. The Association for Peak Oil foresees an imminent peak and Aleklett's paper incorporates new data from Saudi Arabia reinforcing this view. The view is supported by a number of other analyses, reviewed in Boyle and Bentley 2007 contrasting with the conventional view that the peak is far enough away, or that sufficient non-conventional oil reserves can be developed at prices above $40/bbl, to ensure oil-based energy for transport for the foreseeable future.

The models on which the peak oil analyses are based are no more uncertain, and rather less complex, than models of climate change and merit similarly serious consideration. One implication for climate policy is that the rate at which fossil fuels are burnt and the rate at which the stock of carbon dioxide in the atmosphere increases in the near term may merit more attention than the total accumulation of carbon dioxide over the very long term.

Aleklett sees most scenarios for the growth of oil supply, including those employed by the IEA and the Inter-governmental Panel on Climate Change (IPCC), as over-optimistic, and there was some support for the view that they tell us more about where demand "would like to go" than where supply will be able to meet demand.

6. NON-CONVENTIONAL OIL

Oil can be produced profitably at current prices from a range of unconventional sources. The Orinoco Belt in Venezuela is estimated to contain 230 to 300 billion barrels of very heavy crude oil. This is around the size of Saudi Arabia's oil reserves. Canada holds a similar amount of very heavy oil in its tar sand deposits in Alberta. Both deposits are already in production and profitable at prices above $40/bbl. Extraction is expanding rapidly, and the main constraints are environmental, not technological. Canada produced 1M bbl/day in 2005 and expects to produce 2M bbl/day in 2010. The USA, Russia and the Middle East also have large tar sand deposits.

Oil shales hold even larger quantities of potentially recoverable oil, estimated at around 3 000 billion barrels. There are deposits in many countries with large quantities located in the USA, Russia and Brazil. Oil shale is used to fire power generation in a number of countries. It would probably be profitable to produce oil from shale at current prices with currently available technology. Costs would fall substantially with expansion of production.

Coal has been converted to oil by SASOL in South Africa since 1955 and China is currently building two South African designed plants. There are large coal deposits in a wide range of countries around the world[4], with the USA holding the largest reserves. 2007 saw several bills presented to the US Congress for subsidies to finance coal to liquid fuel plants. Operating costs for such plants are covered at oil prices above $40/bbl.

If these non-conventional sources hold the promise of very large quantities of oil to be produced at today's prices they pose serious environmental challenges. Extraction and processing into refinery grade oil requires a lot of extra energy, resulting in more than twice the CO_2 emissions associated with conventional oil (Greene 2007). Because of this, the potential of using nuclear power to provide process energy is being considered for Canadian tar sands. Stripping the forest and soil cover overlying the Canadian tar sands deposits also releases large amounts of greenhouse gases. Production of shale and coal requires large amounts of water, and many of the potential mines are in areas with water resources under stress.

Carbon capture and storage might be employed to reduce the CO_2 emissions associated with tar sand and shale oil production to levels closer to conventional oil but it is as yet an unproven technology. It is difficult to envisage a large scale retrofit programme in Venezuela and Canada if it were to prove viable. Coal-to-liquid fuel production is somewhat more suited to carbon capture as the Fischer-Tropsch process employed produces a very pure waste stream of carbon dioxide.

Aleklett argues (Aleklett 2007b) that applying a peak-oil type analysis to coal and non-conventional oil reserves demonstrates that there are insufficient hydrocarbon resources to produce the CO_2 necessary to increase concentrations in the atmosphere to the levels envisaged by the Inter-Governmental Panel on Climate Change (IPCC). The majority of participants at the Round Table, however, viewed greenhouse gas emissions rather than oil supply shortages as the key long term issue for oil demand from the transport sector. At the same time, as governments begin to develop policies to guard against catastrophic climate change despite large uncertainties in climate modeling, the precautionary principle suggests they might give similar consideration to peak-oil arguments despite uncertainty over the extent of their conservative bias.

7. DOES A PRICE OF $100 A BARREL OF OIL MATTER?

Oil price shocks destroy demand for oil and have repercussions for activity across the economy. They reduce economic activity to the extent that short run substitution and efficiency responses are unable to prevent the cost of production of goods and transport services rising to levels that exceed the willingness of consumers to pay for them. This reduces economic output and results in business failures and unemployment.

In the 1970s, OECD economies were highly vulnerable to external shocks because of widespread government intervention in prices and rigidities in labour and financial markets. Growing inflation meant a sharp downward adjustment was probably inevitable, and this was precipitated by the 1973 oil embargo. Many of the immediate responses of OECD governments exacerbated the crisis: additional price controls on domestic oil production in the USA; restrictions on domestic oil production to preserve resources in Canada.

Today, OECD economies are much less oil intensive and exhibit fewer rigidities. OECD economies are not exposed to inflation (although it is rising) and markets are much freer to adjust to changes in energy prices. The countries where oil prices are determined by governments rather than markets lie in the Middle East and Asia, including China, with artificially low prices one of the factors contributing to strong growth in oil demand in these developing economies. More generally, incomes have increased substantially in most parts of the world and energy costs account for a smaller part of disposable income. Most of the world's economy is therefore much more resilient to price shocks than it was in the 1970s.

The current low level of the dollar against other major currencies is also significant, as oil prices are quoted in dollars throughout the world. The dollar was trading at 0.68 euros in November 2007 compared to 0.99 euros in January 2000, i.e. one third lower. The price for crude oil in euros is thus only two thirds what it might have been if dollar parity had been maintained over the period of steady oil price increases since 2000. Though the yen/dollar exchange rate has only moved 8% since 2000, compared to 1973 the Japanese yen is now worth three times what it was in dollars.

For all these reasons the economic impact of $100/bbl oil is much less than it was in 1979. That said, some economies will feel the effects of today's high oil prices more than others will. US consumers have experienced a bigger impact on prices, especially for transport fuels, because oil is priced in dollars and because excise taxes are a relatively small part of prices at the pump compared to most other OECD countries.

If high oil prices eventually contribute to an economic slowdown in the USA, imports from China will fall. China's growth is highly dependent on its exports, and the USA accounts for the largest part of its trade by volume, although the weak dollar has put Europe in first place in trade by value (Financial Times 10.12.2007). China is also exposed to high international oil prices because the government controls domestic oil product prices at levels currently below cost. It will be forced to pay refiners large sums in compensation so long as prices stay high. This combination of factors could contribute to falling prices in the next few years.

8. TRANSPORT SECTOR RESPONSES TO CHANGES IN OIL PRICES

Transport is the one sector of the economy where substitution with other fuels has been negligible. Consumer responses to changes in fuel prices are often measured through elasticities. There is considerable agreement that the price elasticity of fuel demand is fairly low, meaning that prices have no big impact on demand – but “no big impact” is different from “no impact”. The long run elasticity of fuel demand has historically been in the range of -0.4 to -0.6. Since the absolute value of the elasticity is below one, fuel consumption declines when prices rise but expenditures increase. The resulting shifts in allocation of expenditure to travel from other goods and services depress consumption in other parts of the economy, and result in a transfer of wealth to domestic and foreign oil producers.

Higher fuel prices affect fuel demand through two main channels. First, consumers respond by driving less. Second, they invest more in fuel economy, i.e. in more fuel efficient vehicles. Recent evidence for the US (Small and Van Dender, 2007) suggests that the relative importance of those two effects has changed as incomes increased: the responsiveness in terms of reduced driving has become substantially smaller, so that a bigger share of the total response comes through improved fuel economy.

Note that smaller responses in terms of driving imply a more limited overall fuel price elasticity of demand, around -0.24 instead of -0.36 for the US in 2000-2004; and price effects are counteracted by the income effect, which implies growing consumption as incomes rise.

It should be emphasized that elasticities of demand refer to consumer prices of fuel. Gasoline and diesel are taxed at much higher rates than oil products for use in other sectors, especially in Europe and Japan. Prices for gasoline after tax currently equate to over $300/bbl in many European countries. The higher consumer prices in Europe and Japan are one reason why elasticities in these parts of the world may be higher than those in the US. Another reason is that more European and Japanese drivers have access to alternative transport modes than US drivers. Slightly lower real incomes contribute to higher elasticities as well. On the other hand, more US households have access to several vehicles, providing the opportunity to switch to a more fuel efficient vehicle when oil prices are high. Although differences in elasticities between the US and Europe or Japan are likely to be small, it will not be entirely clear that the finding of declining elasticities in the US is transferable to other countries without empirical studies in those countries.

Freight transport is less affected by oil price increases than private car use as fuel accounts for only a small part of the total cost of producing most goods. Salaries, vehicles and tax are larger items of expenditure than fuel for transport companies. In France it is estimated that the cost of crude oil would have to increase eight fold to double the cost of road freight transport (Chevroulet 2007). The difficulty for freight transport companies is primarily the delay in passing on fuel costs to clients in periods when prices rise rapidly; contracts cover extended periods and do not always provide for fuel costs to be passed on until renegotiation of the contract itself.

9. MOTIVATING TRANSPORT POLICIES – MARKET FAILURES

Transport generates a range of social costs that are not taken into account by consumers or firms when they decide on how much and what kind of transport to use. Such external costs sometimes justify policy intervention because market outcomes are less than optimal. The main external costs are related to accidents, climate change, congestion and local air pollution. Some of these costs (e.g. congestion) are fairly well understood and relatively accurately measured. Others, notably the costs of climate change, are poorly understood and their measurement continues to generate controversy.[5]

Debate at the Round Table highlighted the substantial uncertainty about the future availability of oil and the prices at which it will be sold. Part of the price uncertainty relates to OPEC's market power. But are uncertainty and import-dependency a basis for government intervention in energy or transport markets?

Uncertainty is pervasive throughout the economy, and not in itself a source of market failure. As long as both firms and consumers make decisions on the best available information markets respond optimally to uncertainty. Despite large uncertainties, oil companies do invest in exploration and production and in refinery capacity. The clearest rationale for government intervention is thus ensuring high quality information is widely available.[6]

Oil dependency is primarily an issue of market power. Concentration of oil production in the hands of a cartel that explicitly aims to control prices is a clear case of market failure. Despite government and private sector efforts to diversify sources of oil supply, concentration of market power in the Middle East is expected to grow rather than diminish.

There is also an externality dimension to oil dependence. The USA is a very large consumer and importer of oil so probably enjoys a degree of monopsony power on the world oil market; lower US demand reduces world prices. Individual US consumers ignore this effect when deciding on their purchases of oil and of vehicles and other oil consuming equipment. This potential monopsony effect is therefore external to the market. Without government intervention its potential benefits will be foregone.

Another dimension to oil import dependency is the transfer of resources from importing to exporting countries. In strict economic terms transfers are not of particular concern because oil revenues will eventually be recycled to the oil importing countries through purchases of goods and services and through investment. But with high oil prices the transfers are very large, politically highly visible and they can create large temporary imbalances.

Policies to reduce market power through oil substitution and fuel efficiency are the most relevant responses to oil dependency although it would be possible to transfer some of the economic rent from oil production to the importing countries through additional taxes on oil product consumption, albeit at the risk of pushing prices even higher.

10. POLICY INSTRUMENTS

Fuel excise duty and carbon tax

Excise duty on transport fuels is widely used in OECD countries as a reliable source of government income because of the relatively low price elasticities of demand. The overall effect on oil prices of simultaneous attempts by OPEC to maximise its profits and by oil importing countries to increase fuel taxes is not easy to predict. It is conceivable that higher fuel taxes in the USA would increase welfare if accompanied by reductions in taxes on labour and capital. In addition, such tax increases would reduce some of the rent from oil production accruing to oil exporting countries, because reduced consumption in the USA eases pressure on world prices. Note that at present the reverse situation applies. Fuel excise taxes have been stable in nominal terms in the US and many other OECD countries for the last 5-10 years, eroding their value in real terms.

A number of governments have responded to oil price increases with small cuts in fuel excise tax. The potential to shield consumers in this way is, however, limited by the size and the duration of the impact on government finance. It is also counterproductive as it reduces incentives for fuel conservation and dampens consumer response to oil price increases. Not only does this interfere with the response, it also reduces the price elasticity operating on the oil exporting countries and thus increases their market power.

Governments are not likely to increase fuel taxes when oil prices are rising as this would exacerbate the short run impacts of high oil prices. It might, however, be possible to increase excise taxes when prices fall.

A tax on carbon would have a very similar effect to fuel excise duty in transport markets, as non-carbon based fuels are not likely to gain a large market share soon. The main difference is that a carbon tax would apply equally to all sectors of the economy whereas current taxes on oil products differ enormously between sectors. For example, domestic heating oil is normally taxed at very low rates in comparison to auto diesel, which is a very similar product, just put to a different use. Tax subsidies for diesel compared to gasoline would also disappear, as on a volumetric basis diesel would attract a slightly higher carbon tax than gasoline.

A Pigouvian carbon tax to internalise the social costs of CO_2 emissions, applicable at the same rate to all sectors of the economy and applied in a large number of countries, would be the most efficient policy response to the threat of climate change. Setting the rate for such a tax is a political exercise because of the very real uncertainties in estimating the costs of climate change through its physical impacts on sea level and the weather and consequent effects on crop production, river flows, ecosystems, health and the frequency and intensity of natural disasters related to the weather. Proxies have been calculated from the expected costs of expenditures to reduce emissions to rates that would stabilise the accumulation of CO_2 in the atmosphere at a level believed sufficient to avoid catastrophic climate change. The most influential recent report on climate policy, the Stern Report (Stern 2006), estimated total damage costs from future warming at 5-20% of world GDP in perpetuity and recommends a current social cost equivalent to $311 per ton of carbon (Euros 60 per ton of CO_2)

according to calculations by Resources for the Future (Harrington *et al.,* 2006). This is much larger than some other values frequently employed, such as the average level of trading for carbon permits in the second session of the European Trading System (around Euro 20 per ton)[7] but it is still much lower than the level of fuel excise tax in any European country. For example, UK fuel excise duty, at the top of the range in Europe, of Euros 0.70 per litre equates to Euros 304/ton CO_2 for gasoline and Euros 270/ton CO_2 for diesel; French excise duty on gasoline of Euros 0.60 per litre equates to Euros 259/ton CO_2 and excise duty on diesel of Euros 0.43 per litre equates to Euros 163/ton CO_2.

Table 1. **Fuel tax rates and shadow prices for CO_2**

Tax / Valuation	**Euros / ton CO_2**
ETS trading price	**20**
US gasoline tax	37
US diesel tax	37
Stern Report valuation	**60**
French diesel tax	163
French gasoline tax	260
UK duty: diesel	270
UK duty: gasoline	304

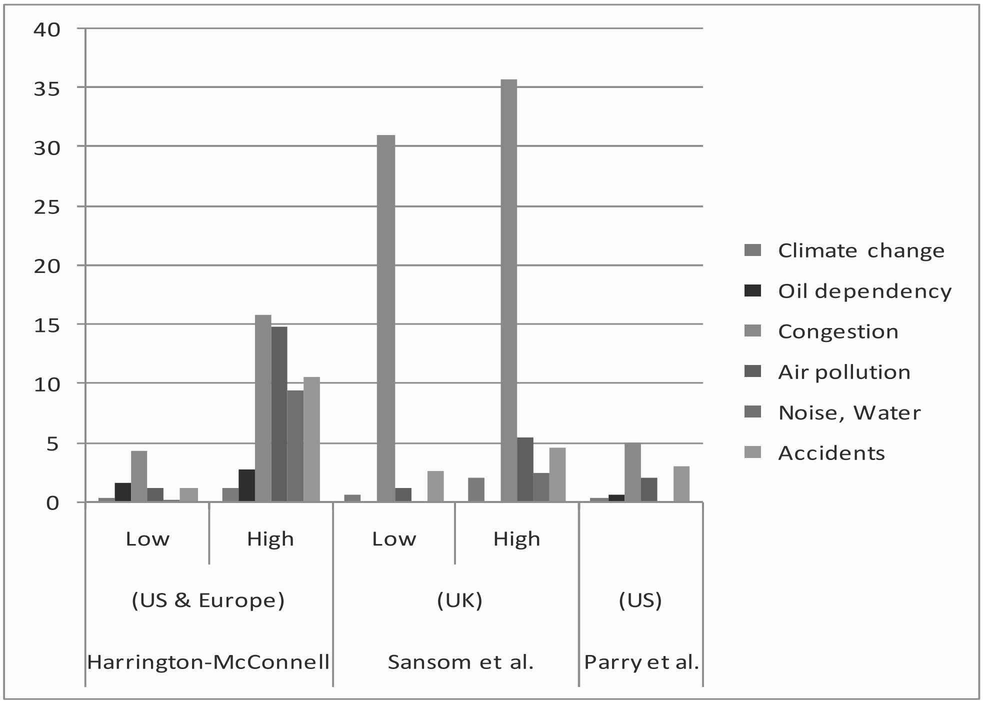
This begs the question of what fuel excise duties are for. In the USA federal fuel duties are earmarked for the Highway Trust Fund, which finances road and transit projects, and which sees real revenues declining because of falling real gas taxes. Fuel taxes are not hypothecated in most other countries, but instead contribute to general revenue. As long as sophisticated road-pricing systems are the exception rather than the rule, a reasonable system of road charges would see the fixed costs of road provision covered from general revenue[8] and the variable costs of road use paid through variable charges, such as fuel tax. The variable costs include road maintenance (as far as related to use and not the weather) and the external costs of greenhouse gas emissions, local air pollution, accidents and congestion[9]. In high fuel excise tax countries such as the UK research has estimated that charges currently roughly balance costs, even if there are mismatches in their differentiation by type of vehicle, location and time of use (Sansom 2001). Parry and Small (2005) found UK fuel taxes to be too high and those in the US too low, taking this "second-best" approach to relating fuel taxes to external costs.

At the same time, most studies of the external costs of road use find CO_2 emissions to be small relative to other types of externality, especially congestion (Figures 3 and 4). This is not to say that the cost of climate change is not large, rather there are other more pressing market failures in transport.

Taxes on transport fuels can perform three functions:

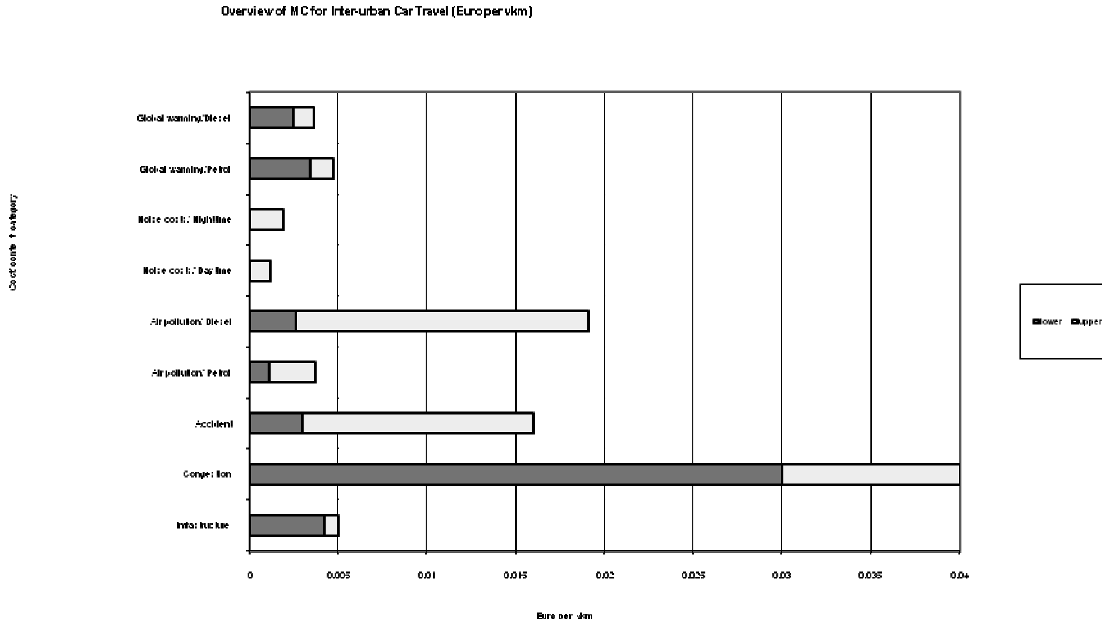
- The Pigouvian objective of internalising external costs;
- The Ramsey objective of providing public revenues in the least allocatively distorting manner. Since fuel taxes are changed in a context of pre-existing taxes, the relevant concern here is how the change exacerbates or relieves the allocational distortions of these pre-existing taxes. Labour taxes are particularly distorting, so the issue becomes whether higher fuel taxes lead to higher or lower real wages, and this depends as much on how revenues are used as on the tax change itself;
- A distributional objective by attempting to transfer rents from governments in oil exporting countries to governments in net oil importing countries.
- If a fuel excise duty were to be employed to achieve all three objectives, how should its rate be set? In general, this depends on the weights given to the various functions, which in turn reflects policy objectives. When government cares strongly about revenues, high fuel taxes seem justified to the extent they offset increases in labour taxes. This may **reflect European practice.**

Figure 3. **CO_2 relative to other external costs** (US cents/mile)



Source: Small and Van Dender (2007).

Figure 4. **Overview of MC for interurban car travel (Euros per v-km)**



Source: Nash (2003).

Vehicle efficiency regulations

In relation to oil import dependency it is not clear from the discussion above that taxation is an appropriate instrument to address either market power or the external benefits of reducing fuel consumption. Alternative policies to promote fuel efficiency are indicated, primarily fuel efficiency regulations.

Intervention to promote fuel efficiency is frequently argued for on the basis that consumers undervalue fuel savings when they purchase cars (and other equipment) because they employ higher discount rates than socially optimal (their planning horizon is shorter than that of the government). Consumers make decisions on how much fuel economy to buy in a context of combined uncertainty and risk aversion. This leads to lower fuel economy compared to a risk-neutral environment but is not in itself a market failure if we assume consumers are adequately informed of the cost of running a car (and there is a wealth of car magazines available to inform car buyers on this point). However, there is a case for government intervention effectively to substitute a social discount rate for the shorter, typical private discount rates applied by consumers in making decisions on car purchase.

Regulatory emissions limits have been employed fairly successfully to address local air pollution externalities. They can also be employed in the case of CO_2 emissions and equivalent regulations were introduced in response to the oil price rises of the 1970s in the USA as Corporate Average Fuel Efficiency (CAFE) regulations.

Compared to a pure carbon tax, regulations have the drawback that they are sector specific and tend to favour one technology over another according to the level at which they are set and the way in which they are measured. Regulations have to be designed carefully to avoid perverse effects. For example, differentiating CO_2 emissions standards according to vehicle class or weight in an attempt to avoid one manufacturer facing higher costs than another can provide perverse incentives that favour high emission vehicles. This was the case with the US CAFE regulations in force until 2007, where weaker standards for light trucks were instrumental in stimulating a shift in demand from conventional cars to SUVs. Curvilinear rather than stepwise differentiation can reduce the problem, but can still reduce incentives for cutting emissions through weight reduction – where there is a large, relatively low cost potential for savings (see Plotkin 2007 and OECD/ITF 2008 for a more detailed discussion). Differentiation according to vehicle “footprint” (wheelbase x axle width) is a somewhat less distorting approach because there are larger costs for manufacturers associated with changing wheelbase. Allowing weight to increase can actually cut costs. Other constraints also make it difficult to increase vehicle footprint, for example the size of typical parking spaces in underground garages and multi-storey car parks.

Regulations also entail monitoring and enforcement costs that are avoided with simple taxes. Regulations do, however, have some advantages compared to taxes, not least in terms of political acceptability.

Using a standard instead of a tax also has the advantage of reducing uncertainty for vehicle manufacturers in the sense that they can be relatively certain how both consumers and competitors will respond to a standard, compared with much larger uncertainty under a tax policy. This certainty facilitates the large investments required to introduce new generations of fuel efficient technologies.

Regulatory standards for CO_2 emissions are undermined to some extent by the rebound effect. By reducing average fuel consumption they reduce the costs of driving, other things being equal, which will provide an incentive to drive more often and further, partially off-setting the impact of the regulation. To correct for this effect it is possible to combine regulatory standards with a carbon tax designed to compensate for the fuel cost savings otherwise engendered by the standard. A combination of vehicle standards and carbon tax is also indicated as regulations alone risk simply postponing emissions of CO_2 rather than restricting the ultimate quantity of CO_2 emitted from the world’s stock of crude oil to an acceptable (efficient) level, which a Pigouvian tax should achieve if the price can be based on reasonably accurate damage estimates.

A note of warning was sounded at the Round Table, however, over combining too many instruments to achieve greenhouse gas mitigation and oil security objectives. A proliferation of instruments results in a lack of transparency and difficulty in tracing the effects of interventions and increases the cost of implementation and enforcement, ultimately undermining cost-effectiveness. This does not rule out using complementary instruments but underlines the need to understand how transport, environment and energy policies interact. Effective and efficient combinations of instruments are examined in a companion publication (OECD/ITF, 2008).

11. DESIGNING TRANSPORT POLICIES: THE NEED FOR INTEGRATING TRANSPORT, ENVIRONMENT AND ENERGY DIMENSIONS

There are potential trade-offs to be made in addressing the failures that affect oil and transport markets. The current structure of oil supply, with production concentrated in the hands of a cartel, suppresses oil demand and in this respect contributes to mitigating CO_2 emissions. Some policies to weaken OPEC market power and reduce oil prices could undermine policy towards climate change.

Promoting non-conventional oil, through subsidies for oil shale or coal-to-oil plants, as demanded by a number of bills presented to the US Congress in 2007, could reduce OPEC market power if a large enough part of US oil supply was provided from these plants but it would massively increase CO_2 emissions. It should be noted that with non-conventional oil production on a smaller scale, OPEC would continue to control prices and the non-conventional oil would be priced at the level of OPEC oil. Support for non-conventional oil would simply represent a transfer of resources from US tax-payers and oil consumers to oil shale and coal-to-oil producers.

Transport, oil and environmental policies also interact in more subtle ways. Fuel specifications have played a significant part in the costs of oil refining, the availability of oil products and the price of oil products in recent decades. For example, California's fuel specifications related to environmental protection isolate the local market from world oil products markets. Local refiners enjoy the protection that this provides and gasoline trades in Singapore at $10/bbl below the wholesale price in California. Mismatches in product standards fragment markets and even if the effect is not as marked in other parts of the world this adds significantly to oil product prices everywhere.

Environmental regulations have sharply reduced the sulphur content of gasoline and diesel to reduce tailpipe emissions of sulphur dioxide, particulates and CO_2. Current engine technologies increase NOx emissions when optimized to reduce fuel consumption. This requires NOx reduction catalysers for the exhaust that are extremely sensitive to sulphur poisoning. Stripping sulphur out of oil at the refinery requires a lot of energy, resulting in additional emissions of CO_2 from the refinery itself. The balance in CO_2 gains and losses between car exhaust pipe and refinery emissions is shifting as sour (high sulphur) crudes account for an increasing share of the refining slate. Demand for low sulphur diesel is one of the factors promoting production of biodiesel in Europe, as it is completely free of sulphur. Current biodiesel production may be associated with an increase rather than a decrease in greenhouse gas emissions compared to conventional diesel, taking into account N_2O emissions from the cultivation of feedstocks (OECD/ITF 2007).

Two thirds of the progress in reducing CO_2 emissions from new cars in the EU since the voluntary agreements with car manufacturers entered into force (in 1998) have been the result of a shift from gasoline to diesel engines facilitated by lower fuel taxes on diesel than gasoline. This has seen diesel consumption rise inexorably and it now outsells gasoline in Europe. The shift has created a large imbalance in Europe's refining industry, with excess gasoline sold to the USA and diesel imported from Russia. This has implications for CO_2 emissions as well as prices. Crude oil contains a mixture of different hydrocarbons. The mix of useful products that can be separated out with minimal energy input is determined by the nature of the crude. There is a degree of flexibility in the product mix produced, but shifting the mix requires large amounts of additional energy input. An increasing number of refineries in Europe convert heavy fuel oil (for which the market is weak most years) into diesel, but at the cost of additional CO_2 emissions from these refineries. The diesel-gasoline balance has been pushed to its limits in world refining markets. If the US government were to adopt policies to promote diesel cars[10] diesel prices would rise significantly and CO_2 emissions would increase as additional crude oil, with deeper conversion processing, would be required to supply the market. It would not be possible to achieve the European degree of dieselization in any other major car market.

Regulatory standards or taxes intended to internalise the costs of greenhouse gas emissions thus need to be designed not only to avoid bias towards promoting particular technologies (in this case diesel engines) but also to avoid simply shifting emissions from one point (tailpipe exhaust) to another (refinery smoke stacks) and exacerbating other external costs – in this case NOx emissions, as diesel engines produce higher levels of NOx than gasoline engines and are generally subject to weaker emissions standards. These are basic tenants for the design of interventions to protect the environment but they are frequently overlooked in practice. Fuel taxes in Europe that favor diesel clearly fail the test.

NOTES

1. US data suggests that with rising incomes, price elasticities for private road passenger transport have declined. Consequently, there has been a change in the way drivers respond to higher fuel prices, with the vehicle-kilometres driven less sensitive to the price of fuel than the fuel efficiency of vehicles.

2. Although the 1973 Arab-Israeli War and subsequent oil embargo was preceded by re-negotiations of oil concessions and nationalisations of oil companies in the Middle East and Africa, and by OPEC coordinating oil production tax and price increases in response to a weak dollar.

3. Known as "backwardisation".

4. Though Aleklett believes that coal production, like oil, has peaked.

5. The consequences of climate change are at best understood in a probabilistic sense. In addition, since some of the more catastrophic consequences are likely to take place in the far future, there is the problem of converting these costs to present values. Such conversion inevitably requires judgments on intergenerational equity, and it was pointed out that the well-known Stern report implies substantial sacrifices by current generations to improve the welfare of more wealthy future generations.

6. While the private sector produces large amounts of oil market information on a commercial basis, the data and analysis of the IEA and of national administrations, such as the EIA in the USA, is essential in providing a complete and authoritative picture. The work of university researchers on peak oil has been invaluable in improving the understanding of data on oil reserves reported by oil companies.

7. Note the price is determined by the amount of carbon allowed to be emitted by the participants in the scheme, currently determined largely on the basis of what they emitted prior to the scheme. Such "grandfathering" of emissions rights weakens the effectiveness of the system to cut emissions and illustrates the artificial nature of the price of carbon that results. The EU plans to reduce the cap on the amount of carbon traded in the system, which will force the price up.

8. Or possibly from fixed transport charges, such as annual circulation taxes.

9. Though fuel tax is not the best targeted instrument for some of these costs.

10. Policies adopted initially in Europe to promote producers of diesel engines.

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INTRODUCTORY REPORTS

PEAK OIL AND THE EVOLVING STRATEGIES OF OIL IMPORTING AND EXPORTING COUNTRIES:

Facing the Hard Truth about an Import Decline for the OECD Countries

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SUMMARY

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ABSTRACT

Statistical trends for oil intensity from individual countries and groups of countries show that an average increase in GDP of 3% per annum equates to a projected demand for liquids of 101 million barrels per day (Mbpd) by the year 2030. The following analysis shows that this demand cannot be fulfilled by production from current reserves and expected new discoveries.

Two models are considered for assessing peaks in oil production: the depletion model (DM), and the giant field model (GFM). The DM model shows peak oil (the maximum rate of production) in the year 2011 with 90 Mbpd. Adding GFM we develop a "worst case" scenario of a plateau in production for the next five to seven years at a rate of 84 Mbpd. A more optimistic case in the "Giant High Case" scenario is a peak in 2012 at 94 Mbpd. A less steep increase in demand can move the peak to 2018. Both models show an oil production rate in the order of 50-60 Mbpd by 2030.

The demand for oil from countries that are importers is forecast to increase from current import levels of 50 Mbpd to 80 Mbpd. Saudi Arabia, Russia and Norway, today's largest oil exporters, will experience a decline in their export volumes in the order of 4 to 6 Mbpd by 2030. The projected shortfall cannot be offset by exports from other regions.

In a business-as-usual case, the shortage of fossil fuel liquids for transportation will be substantial by the year 2030. The necessary decisions for the economic transformation required to mitigate this decline in available oil supply should already have been made and efforts to deploy solutions under way.

We have climbed high on the "oil ladder" and yet we must descend one way or another. It may be too late for a gentle descent, but there may still be time to build a thick crash mat to cushion the fall.

1. INTRODUCTION

1.1. Mission

Modern civilization has become increasingly dependent upon oil over the past century, with oil now recognized as the most important global commodity. Currently the oil and gas industry has even surpassed agriculture as the world's single biggest industry. At $70 per barrel, the value of the world's crude oil business alone is over $2 trillion/year. However, crude oil is far from uniformly distributed around the world, and only a limited number of countries are significant producers. This fact divides the world into oil exporting and oil importing countries. The majority of the OECD countries import oil, and these economies will not function without global security in the oil export market. Unfortunately, peak oil will create a progressively more insecure export market.

The study contained within this paper will address peak oil and the evolving strategies of oil importing and exporting countries.

1.2 Major articles by Uppsala Hydrocarbon Depletion Study Group

The findings in this report are mainly based on research done by Uppsala Hydrocarbon Depletion Study Group, Uppsala University, Sweden, and the following works will be used as main references:

[1.1] K. Aleklett and C.J. Campbell; The Peak and Decline of World Oil and Gas Production, *Minerals & Energy* 18 (2003) 5-20. http://www.tsl.uu.se/uhdsg/Publications/Minerals&Energy_2003.doc)

[1.2] K. Aleklett; Testimony on Peak Oil, presented before the House Subcommittee on Energy and Air Quality, Washington DC, USA, December 7, 2005. http://energycommerce.house.gov/reparchives/108/Hearings/12072005hearing1733/Aleklett2770.htm

[1.3] K. Aleklett; Oil: A Bumpy Road Ahead, *World Watch* 19-1 (2006), p. 10, (the article is available at http://www.peakoil.net/uhdsg/WorldWatch_2006_Jan.doc)

[1.4] K. Aleklett; Oil production limits mean opportunities, conservation, *Oil & Gas Journal*, 104-31 (2006). http://www.tsl.uu.se/uhdsg/Publications/OGJ_Aug_21_2006.doc)

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[1.10] Mikael Höök, Werner Zittel, Jörg Schindler and Kjell Aleklett, A resource-driven forecast for future global coal production, Submitted to *Energy Policy* (2007); http://www.tsl.uu.se/uhdsg/Publications.html

1.3 Peak oil and today's society

The Association for the Study of Peak Oil and Gas (ASPO) introduced the term "peak oil" in 2001, with Colin Campbell (founder of ASPO) defining it thus:

"The term Peak Oil refers to the maximum rate of the production of oil in any area under consideration, recognising that it is a finite natural resource, subject to depletion."

When the International Energy Agency (IEA) presented the World Energy Outlook 2004 (WEO 2004) the term peak oil was discussed as a possible future scenario. In the summary, the IEA stated: "*Production of conventional oil will not peak before 2030 if the necessary investments are made.*" However, when we look further, we find that in Chapter 3 a peak in 2030 is premised on a USGS (United States Geological Survey) "mean estimate" of 2 626 billion barrels of remaining conventional oil. In WEO 2004, the IEA adds the caveat that if this estimate should prove too high, then "*the peak of production would come by 2015 or before*". The Uppsala Hydrocarbon Depletion Study Group (UHDSG based at Uppsala University in Sweden) has shown, in an article discussing WEO 2004, that oil production of 120.3 million barrels per day in 2030 is improbable [1.11]. Subsequent events and reports have demonstrated the importance of peak oil as a central theme around which economic development must be discussed.

Between July 2005 and December 2006, the United States Government Accountability Office (GAO) investigated issues related to peak oil and in February 2007 released a report to Congressional Requesters entitled "Crude Oil – Uncertainty about Future Oil Supply Makes It Important to Develop a Strategy for Addressing a Peak and Decline in Oil Production" [1.12]. The fact that this GAO study took nearly two years to be completed shows the seriousness with which US policy-makers treat peak oil.

Furthermore, on October 5, 2005 the US Secretary of Energy, Samuel W. Bodman, requested that the National Petroleum Council (NPC) undertake a study on the availability of global oil and natural gas [1.12]. This letter helps demonstrate the political levels that peak oil has now reached:

"Dear Mr. Raymond,

Perspectives vary widely on the ability of supply to keep pace with growing world demand for oil and natural gas, the point in time at which global oil production will plateau and then begin to decline ("peak oil"), the implications these may have for the U.S. and world economies, and what steps should be taken to achieve more positive outcomes.

Accordingly, I request the National Petroleum Council, NPC, conduct a study on global oil and natural gas supply. Key questions to be addressed in the study may include:

- *What does the future hold for global oil and natural gas supply?*
- *Can incremental oil and natural gas supply be brought on-line, on-time, and at a reasonable price to meet future demand without jeopardizing economic growth?*
- *What oil and gas supply strategies and/or demand side strategies does the Council recommend the U.S. pursue to ensure greater economic stability and prosperity?*

……..I look forward to reviewing the Council's proposed study committee and detailed study plan.

Sincerely,
Samuel W. Bodman"

On July 18, 2007, the NPC accepted the report, "Facing the Hard Truths about Energy", and presented this to the Secretary of Energy.

December 2005 saw the Swedish Prime Minister, Göran Persson, set up the Commission on Oil Independence. He asked the Commission to present concrete proposals to reduce Sweden's dependence on oil by 2020 and thereby, in this context, significantly reduce the actual consumption of oil in Sweden. The report from 21 June 2006, "Making Sweden an *Oil-Free* Society" [1.14], points out that the peak oil debate in Sweden was the main cause for the appointment of such a commission.

In December 2005, the peak oil discussion had also reached the U.S. House of Representatives and the Subcommittee for Energy and Air Quality. On December 5, as the only non-American citizen, the author was called to deliver a written testimony and invited to Capitol Hill for an oral presentation [1.2].

For obvious reasons, GAO and NPC have concentrated their efforts on the situation in the USA, and before turning to some of the key points in the report it is necessary to place the report in a more OECD-oriented context. In the USA, oil production peaked in 1970 and since then production has seen a steady decline. At the same time, with increasing consumption, the USA is becoming more and more dependent upon imported oil. Within Europe, we witnessed an increase in the production of oil up until the end of the 20th century, but the new millennium has seen this rate of production start to decline. Year by year Europe is steadily growing more dependent on imported oil, just as we have already seen in the USA. Europe is therefore facing the same problems as the USA, outlined in the GAO and NPC reports.

During the time frame 2008-2030 it is expected that all oil-producing countries within the OECD will face the same problems as those that the USA and Europe face today. The hard fact is that OECD countries in general will be more dependent on oil imports in 2030 than they are today.

The outline of this report will concentrate on oil and will have the following structure:

- The future demand for oil.
- How much oil have we found and when did we find it?
- Historical consumption and limits for future consumption.
- Import and export scenarios.
- Production of transport liquids with CTL (coal to liquids) and GTL (gas to liquids).
- Possible strategies of oil importing and oil exporting countries.
- Awareness of peak oil.

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2. FUTURE DEMAND FOR OIL

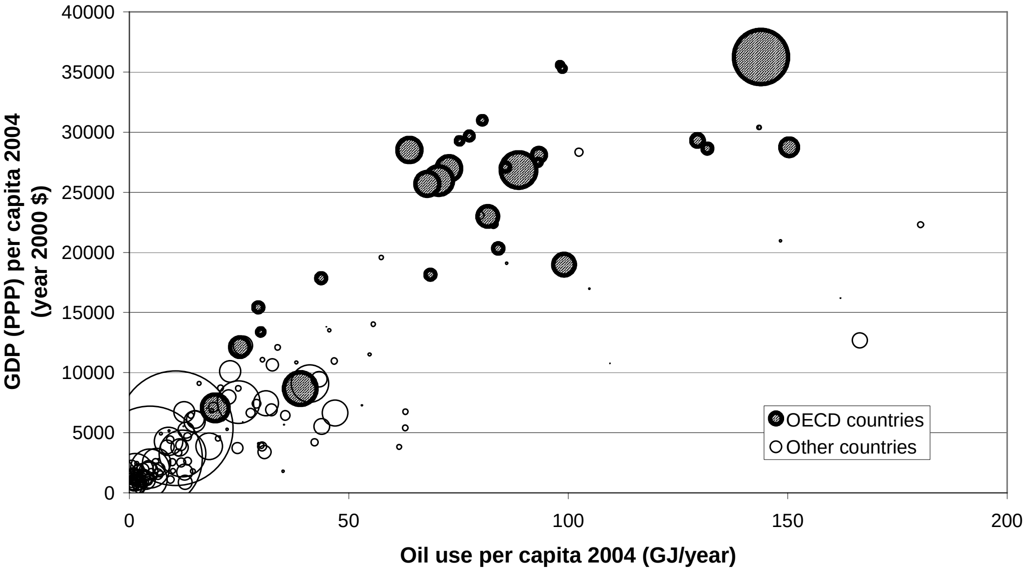
2.1. Future oil demand forecasts by IEA and EIA

In the World Energy Outlook 2004 (WEO 2004), published by the International Energy Agency (IEA [2.1]), the correlation between GDP growth and increases in oil consumption was discussed. The conclusion was that over a 20-year average an increase of 3% in GDP was correlated with a global increase in oil consumption of 1.6% per year. Starting with a consumption of 77 million barrels per day (Mbpd) for the year 2002, the demand predicted for 2030 is set to be 121.3 Mbpd, an exponential growth over 28 years. Previously in WEO 2001, the final year for the forecast period was 2020 [2.2] and in WEO 2002 the IEA added a further 10 years of exponentially increasing demand [2.3] without considering the implications of peak oil. The next WEO was for 2004 with exponential growth still being utilised for forecasting purposes. We made an analysis showing that this prediction of exponential growth was unrealistic [2.4], an analysis which consequently so disturbed the IEA that they contacted us and requested that the analysis be removed from the Web. However, the analysis remained on the Web and in WEO 2005 the increase in demand was reduced to 1.4%, with demand for 2030 being reduced to 115 Mbpd [2.5]. This number has since remained the official demand figure for the IEA [2.6]. The US Energy Information Administration (EIA [2.7]) has calculated a 118 Mbpd demand for 2030 with OPEC and Non-OPEC production being 57 Mbpd and 61 Mbpd respectively.

2.2. Oil intensity driven demand

The fact that a scaling of GDP is used as a driving force for growth in oil demand has led us to make a detailed study of the correlation between GDP and oil consumption [1.7]. The standard GDP measure is calculated from currency exchange rates, a misleading figure in comparisons between countries, since differences in price levels are not taken into account. The GDP adjusted to Purchasing Power Parity (PPP) addresses this problem and gives a somewhat more accurate picture of relative income levels and standards of living. Throughout this study, real GDP (PPP) at constant year 2000 prices has thus been used instead of unadjusted GDP.

Figure 2.1. **Oil use versus GDP (PPP) per capita in 2004 for all countries with available data**



The size of a circle represents population size. A number of small countries, among which Luxembourg, Singapore, Kuwait and Qatar, have too large an oil consumption to be shown in the graph. The OECD countries are shown as hatched circles and Turkey has the lowest number.

To understand how important oil is for GDP we show in Figure 2.1 the correlation between GDP per person and oil consumption by person. The size of the circle is related to the population in the country. There is no doubt that GDP and oil consumption are strongly correlated. No country has attained a GDP similar to OECD Europe without a significant increase in oil consumption. Presumably, this also applies to Turkey and other countries striving for higher GDP. Historically, countries at the top of the list, like the USA, have used more than a one-to-one correlation for economic growth. For today's expanding economies like China and India, we have a one-to-one correlation [1.7].

Based on the supposition that GDP is the primary driver of oil demand, a simple model of oil demand can be formulated:

$$E_{oil} = (E_{oil}/GDP) * GDP \quad (1)$$

where E_{oil} is the total demand of energy from oil, and (E_{oil}/GDP) is a factor henceforth labelled *"oil intensity" (OI)*. *OI* is in itself a function of a number of factors such as technical efficiency, the structure of GDP, and the relative importance of oil as a primary energy source. Thus, treating *OI* as a straightforward measure of 'efficiency' in oil use, as is done occasionally, is misleading. *OI* is affected by several factors unrelated to efficiency. Constructing a scenario of oil demand using equation (1) only requires scenarios of *GDP* and *OI*, respectively.

Figure 2.2. **Development of oil intensity (OI) in selected countries, 1980-2005** [1.7]

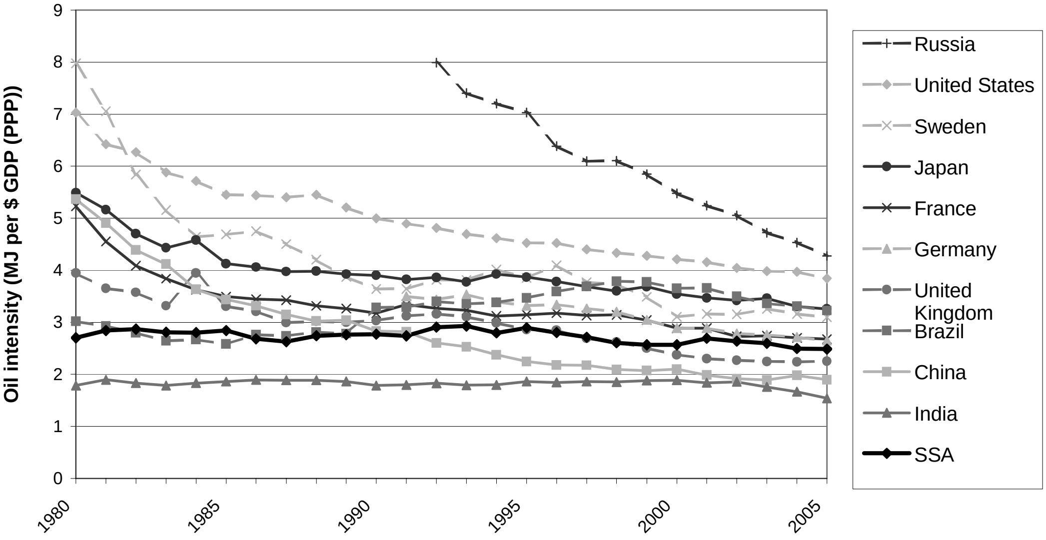


Figure 2.2 shows the development of *OI* in selected countries for 1980-2005: Sub-Saharan Africa, SSA, representing a region without any growth per capita in GDP; China and India with strong growth in GDP; Russia as a transition economy; and some OECD countries.

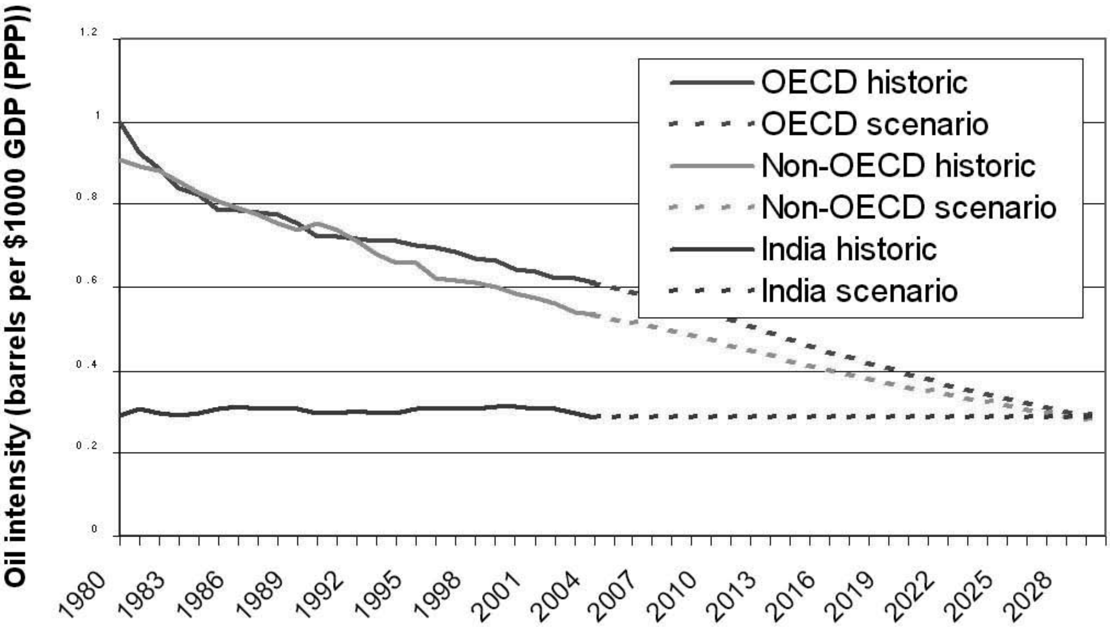
Four observations can be made:

- *OI* has tended to converge towards a common level over time.
- Countries with initially high *OI*, e.g. the United States, Russia, Japan, France, China and Sweden, have declined dramatically.
- Most of the decline in *OI* took place during the first decade of the period, 1980-90, while subsequent decline has been much less dramatic (except in the case of Russia).
- Despite declining *OI* in OECD countries, they are still more oil-intense than India has been throughout the period. SSA also appears to maintain a rather low *OI* by international standards.

The last observation is perhaps counterintuitive. The OECD countries, despite their shift towards service economies, access to various alternative energy sources, technological capabilities, and occasionally explicit policies of reduced oil dependence, have not managed to become less oil intense than the developing economy of India. The radical decline in *OI* that occurred in several countries after 1980 may be interpreted as a response to the record high oil prices of the second oil shock. Conspicuous, though, is that no such price response is visible in SSA, India and Brazil, countries at an already low level of oil intensity. More recently, India has been suspected of underreporting its oil product imports [2.7], which makes it difficult to determine whether the decline in *OI* observed since 2002 is actually genuine.

The bottom line conclusion is that no OECD country has developed an economy that functions at a lower oil intensity than that of India. Regarding the oil intensity of India as the lower limit for the foreseeable future, it is possible to make a scenario of world oil demand based on the future development of oil intensity.

Figure 2.3. **Oil intensity for OECD countries and non-OECD countries compared with the oil intensity of India**



In our forecast we assume that the whole world will have the same oil intensity as India in year 2030. Starting in 2010 the oil intensity for OECD countries has to decrease by 3.2% per year and for the non-OECD countries by 2.7% per year.

If we look at the oil intensity in the OECD and non-OECD countries and compare it with India, it is obvious that the world economy has to be less oil intense. The annual decrease for OECD has to be 3.2% and for non-OECD 2.7%. New technologies, savings, changes of life style, etc., are needed, but let us assume that these are all possible.

In our scenario we assume that the future global increase in GDP of 3% is divided in such a way that OECD countries take 2% and non-OECD 5%. With these numbers, equation 1 will give a demand of 101 Mbpd. This value is 14 Mbpd lower than the IEA forecast and 17 Mbpd lower than the EAI forecast, but we should remember that the cut in oil intensity for most of the countries in the world is a very tough mission.

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3. HOW MUCH OIL HAVE WE FOUND AND WHEN DID WE FIND IT?

The oil production process is based upon the development of oil fields that were originally located by the exploration of potential geological structures. The United States Geological Survey (USGS) has made detailed studies of where conventional oil resources can be found around the world [3.1] and, with the exception of regions around the North Pole, we can conclude that oil companies have been and are looking for oil in all of these regions. When discussing future oil production, it should be further noted that the oil industry is a mature industry, lacking the naiveté of less mature industries.

3.1 Resources and reserves

To better understand how much oil has been found and when it was found, a short review of the various classifications of oil resources and reserves is required. Original resources are the total amount of oil that originally existed in the Earth’s crust. Among the original resources that have been discovered, some are recoverable and some are unrecoverable. Every oil field has a specific recovery factory that is dependent upon the geological condition of the reservoir, but is also affected by technical solutions used in each oil field’s production.

The discovered, recoverable resources are referred to as the Ultimate Recoverable Reserves, URR, being the sum of cumulative production and production from reserves. The discovered, unrecoverable resources are divided into technically recoverable but not economic resources, and unrecoverable resources that are neither technically recoverable nor economic. Future production of oil is therefore dependent on today’s reserves, future economic reserves, and undiscovered oil that can be converted into economic reserves.

However, there is always uncertainty about how much oil in an oil field can actually be recovered. This uncertainty has led to the calculation of reserve figures based upon the probability of extraction, the confidence of recovering a given amount of oil from a given oil field. A reserve estimate followed with, for instance, “P90” means that there is a 90% chance that there is at least as much recoverable oil as the reserve estimate claims.

In addition, industry makes the following division of reserves:

a. Proved reserves: can be estimated with a high degree of certainty to be recoverable. It is likely that the actual remaining quantities recovered will exceed the estimated proved reserves. Proved reserves are labelled 1P.
b. Probable reserves: additional reserves that could be recovered but with less certainty than proved reserves. It is equally likely that the actual quantities recovered will be greater or less than the sum of the estimated Proved + Probable reserves. This sum is labelled 2P.

c. Possible reserves: additional reserves that are less certain to be recovered than probable reserves. It is unlikely that the actual remaining quantities recovered will exceed the sum of the estimated Proved + Probable + Possible reserves. This sum is labelled 3P.

Understanding published statistics of reported reserves is difficult because some publications report only 1P reserves, others report 2P reserves, and yet others report a mixture of 1P, 2P or even 3P reserves [3.2].

As an example, let us take the reserves in Saudi Arabia, and for the purposes of this discussion we will use the data presented by Mahmoud M. Abdul Baqi and Nansen G. Saleri from Saudi Aramco at a presentation in Washington D.C. on February 24 [3.3].

Oil-in-place (OIP) is the estimated total amount of oil that is in the ground before production has started, and OIP for Saudi Arabia is reported to be 700 billion barrels (Gb) (the number 720 Gb has been recently reported in some newspapers). The total production so far is 105 Gb or 15% of the 700 Gb of OIP. The 2P reserves were claimed to be 260 Gb, or 37% of OIP. If we add the fraction produced and the fraction in reserve we obtain a recovery factor of 52% on average for all of the one hundred oilfields in Saudi Arabia.

Leif Magne Merling from Statoil has made a study of recovery factors for thousands of oilfields and in 2004 he reported the average global recovery factor as 29% (and technology may increase this figure to 38% in the future) [3.4]. The P1 number for Saudi Arabia has been reported as 131 Gb, or 19% of OIP [3.3]. This number combined with the produced figure gives a recovery factor of 34%, which is already over the average reported currently.

In the 1980s, the reserves in OPEC countries were reported to have increased by 300 Gb [1.1], even though new discoveries had not been made. We can then treat these increases as new estimates of recovery factors, but the question remains: “can these new high-recovery factors be sustained?” When it comes to planning future liquid production for transport, we should not simply accept this as fact.

3.2 Oilfields

Oilfields come in many different sizes, and of the total number of oil fields in the world, estimated at 47 500, only 507 are considered to be giant oilfields. The definition of a giant oilfield is one that will ultimately produce more than 500 million barrels (Mb) of oil. Uppsala Hydrocarbon Depletion Study Group has made an extensive study of giant oilfields, presented in the thesis of Fredrik Robelius [1.6]. Data and information on giant fields has been collected in a database named “Giant Field Data”. This database includes information on discovery year, year of first production, cumulative production up to 2005 and different URR (Ultimate Recoverable Reserves) estimates.

In this study by the UHDSG, the measure of the size of an oilfield (from which the designation giant is derived) proved to be important and the measure chosen was the URR. Previously, URR was defined as the cumulative production plus the recoverable reserves. Yet the phrase “recoverable reserves” represents a highly dynamic value that consequently affects the URR. In order to minimize the impact of this dynamic aspect of URR, proven plus probable (2P) reserves were used in the study.

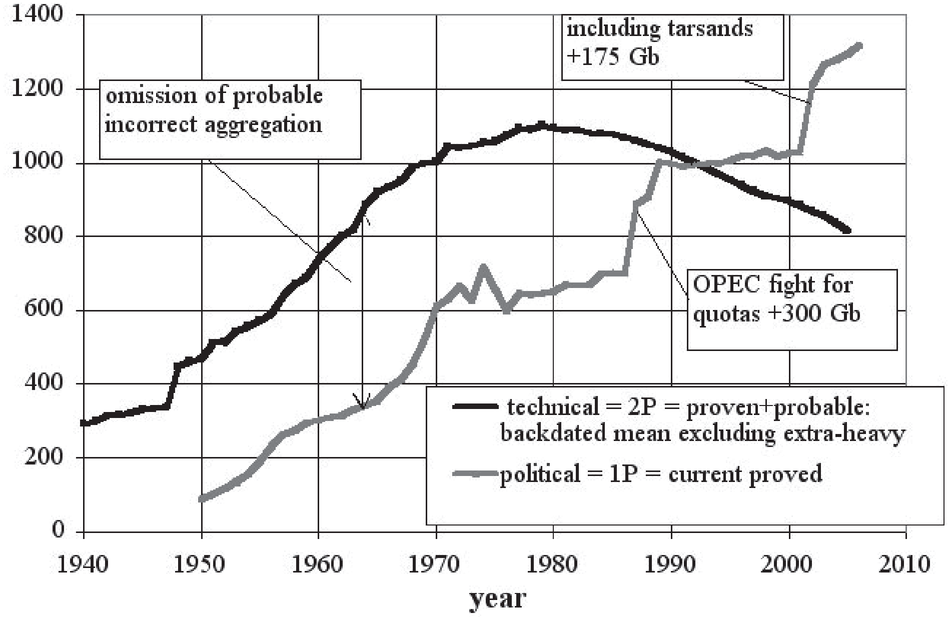
The many different estimates for URR over the last ten years lie in the range of 1 750 to 2 850 Gb. One reason for this wide variation is the diverse types of oil included in the various estimates where, for example, some will include oil sands but other estimates are confined to conventional oil. Moreover, the estimates include oilfields "yet to find in the near future" and obviously this "yet to find" part of the estimate is uncertain, with much controversy revolving around this figure.

An average of the estimates from the last ten years gives a URR value of 2 250 Gb and a similar value is obtained by adding the approximate 1 000 Gb produced to date to the IHS Inc. energy estimate of a remaining 2P reserve of 1 200 Gb [3.10]. According to our database, the URR of the 507 giant oil fields is estimated at between 1 150 and 1 550 Gb; thus, if using 2 250 Gb as a global value of URR, giant fields represent about 55% of the global URR. Giant fields have obviously dominated past production, and future production will continue to be dependent upon these giant oilfields.

3.3 Discovery of crude oil

To estimate how much oil can be produced in the future we need to know how much has been found, when in time it was found, and how much we can expect to find. Every year, the publications *Oil & Gas Journal* [3.5], *BP Statistical Review of World Energy* [3.6] and *World Oil* [3.7] report the figures for production of oil, consumption of oil and oil reserves. The year-by-year calculated reserve from these open databases is a sum of P1 reserves, politically motivated reserves and the Canadian tar sand reserves. Jean Laherrere, former exploration manager for the French oil company, Total, has for many years collected reserve data and presented them in different articles [3.8], [3.9]. Figure 3.1 shows a time series of these reserves (labelled "political") against "technical" reserves. An examination of these "political" reserve numbers would appear to show that reserves are increasing over time.

Figure 3.1. **Global oil reserves in billion barrels (Giga barrels, Gb)** reported as Proven (P1) and Proven + Probable (2P) [3.9]

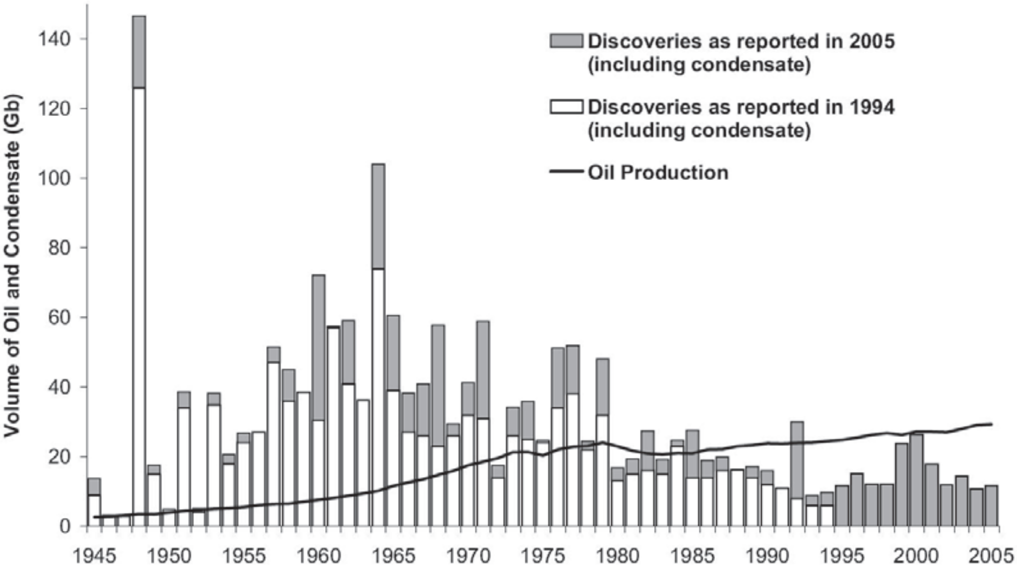


Conversely, examination of those reserves labelled “technical” (backdated 2P reserves excluding extra-heavy oil) provides a completely different picture. Reserves reach a maximum in or around 1980, and from that point in time a clear decline in reserves is observable. Future oil production looks a lot less positive.

The reserve classifications 1P, 2P and 3P were discussed in Section 3.1, and when a new oilfield is discovered estimates are made according to these classifications. These first estimates are defined in the discovery year of that oilfield. During the production phase of the field, typically several years later, more accurate estimates can be made. In a few cases this will reduce the reported size of a field, but normally we will observe a reserve growth. This reserve growth can be due to field extensions, revision of earlier estimates and the availability of new technologies that improve oil recovery. The question is when in time this growth should be reported. Industry databases, such as that of IHS [3.10], locate these changes in field size at the year of discovery. This is known as backdating. In Figure 3.1 the “technical” data points are backdated. This means that all the oil in the field was found the year the field was discovered, with the consequence that the 2P reserves reached a discernible ceiling around the year 1980 and are now in decline.

Figure 3.2 presents the global annual 2P discoveries of both oil and condensate as reported in 1994 and 2005. The difference in the discoveries for a single year between the two reporting periods is the backdated growth of existing oilfields. The fields discovered in the 1960s and 70s were found with less advanced methods than the fields found in the last 10 years, and it is no surprise that we get a more substantial growth in the size of fields for this period. Another important detail exposed by this data is that we will never again find oilfields as numerous and large as we did in the middle of the last century.

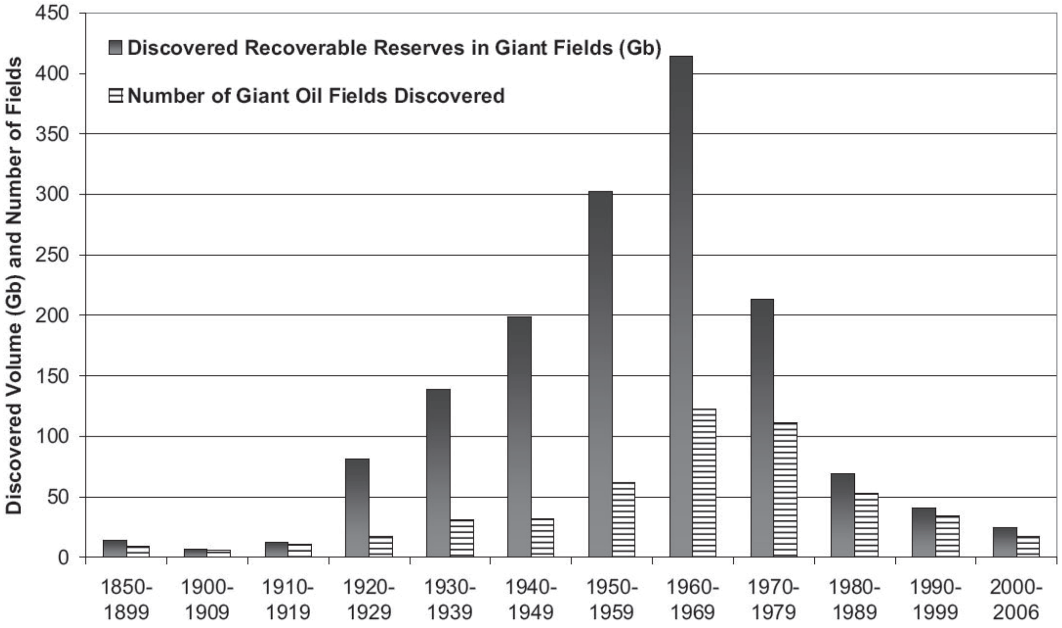
Figure 3.2. **Global annual discoveries of both oil and condensate, as reported in 1994 and 2005, together with oil production in billions of barrels (Gb)**



The difference in reported reserves between 2004 and 2010 is the reserve growth.
Source: Based on data from IHS Energy, ASPO and *Oil & Gas Journal* [1.6]

A separate study of giant oilfield discovery (Figure 3.3) – the fields that today produce more than 50% of the world's crude oil – generates a clearer picture. Although the number of giant oilfields found in the 1990s is similar to the number found in the 1940s, those in the 1940s were on average four times larger than the fields discovered in the 1990s. It is clear that the 1960s represented the golden age of the oil industry, and it is unlikely that these golden times will ever return.

Figure 3.3: **Discovery of giant oil fields per decade, with respect to number and URR**

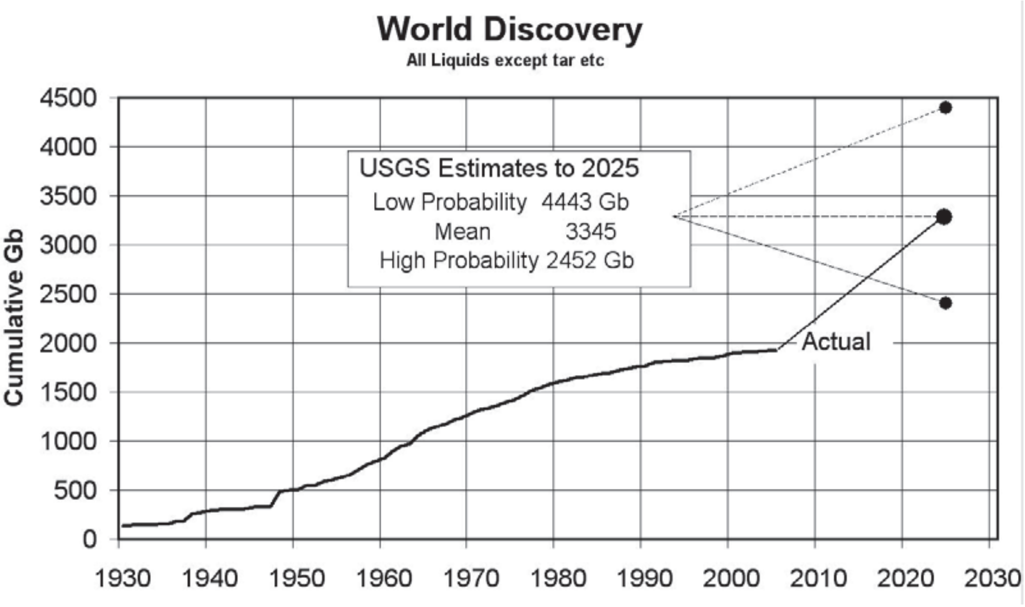


The most optimistic URR estimates have been used [1.6].

By adding the discoveries given in Figure 3.2 and discoveries from the beginning of the 20th century, we get total cumulative discoveries to date of close to 1 800 Gb. The cumulative consumption of crude oil has reached 1 000 Gb, and from this we get 800 Gb of reserves, the same number as in Figure 3.1. Yet in a report dated 2000, the US Geological Survey estimated that by 2025 we should have found 3 345 Gb [3.1]. This number was subsequently used by the IEA for their base case scenario for future oil production. Following the statistical trends evident in Figure 3.4, it is unlikely that the cumulative discovery rate will have reached the predicted 3 345 Gb by 2025.

The discovery trend presented in Figure 3.2 shows a declining rate of discovery and the decade discovery rate displays a logarithmic decline. Extrapolation of this trend for the next thirty years provides an expected 150 Gb of discoveries in new oilfields. If we assume that the growth in existing oilfields will also be in the order of 150 Gb, we obtain a total cumulative value of discovered crude oil by the year 2030 of 2100 Gb. This is far from the number provided by the USGS and used by the IEA for their scenario analysis.

Figure 3.4: **The global cumulative crude oil discoveries [1.1] and the USGS estimate of crude oil discovery in year 2025**



At the ASPO-6 Conference in Cork, 16-17 September 2007, Ray Leonard presented data from the 2006 Hedberg Conference [3.12]. This was a gathering of experts from private industry, state companies, academia and consultants to discuss world oil reserves and the potential for future growth. Attendees included representatives of the six largest private companies, major independents, OPEC, major state companies (Aramco, Petrobras, Petronas, Pemex), state organisations and “think-tanks”. All attendees were specifically invited and had to make presentations on their areas of expertise. The press was not allowed access, and presentations were only shared among participants so as to permit more open discussion.

For seven regions – West Siberia, Niger Delta, SW Africa, North Caspian, Offshore Brazil and Saudi Arabia – estimates by industry experts of growth from exploration were compared with estimates from the USGS. Ray Leonard pointed out that he personally had made the estimate for West Siberia, for which USGS have reported 55 Gb, but he could perceive only 15% of the figure provided by the USGS as being realistic. For the seven regions explored, the USGS has a combined figure of 368 Gb, but experts from within the industry could only see 36% of that as a realistic calculation. *If this holds for the rest of the world, the conclusion is that the IEA must stop using data from the USGS in scenarios for future oil production.*

3.4 Discovery of heavy oil

The oil resource bases in Alberta, Canada and the Orinoco Belt, Venezuela are usually referred to as unconventional oils. In an historical context, conventional drilling and production methods could not be used to produce the oil; hence the term “unconventional”. The main reasons for this are the density and high viscosity of the oil.

Heavy oil is not limited to these two areas and heavy oilfields occur all over the world, such as the Kern River, California, Captain in the UK section of the North Sea, and Duri, Indonesia. However, the two largest accumulations of heavy oil by far are in the Orinoco Belt and Alberta. Oil from Orinoco is usually called heavy oil, while the extracted fluid from the oil sands in Alberta is referred to as bitumen.

Established reserves in the Orinoco Belt equal 37 Gb, but actual oil in place is much larger and there is therefore the potential for reserve growth in the future. The reserves in Alberta can be divided into two fractions: a smaller part with 32 Gb that can be mined, and a larger part, 142 Gb, that can be extracted by the "*in situ* method" [1.7].

3.5 References

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4. HISTORICAL CONSUMPTION AND LIMITS FOR FUTURE CONSUMPTION

The *BP Statistical Review of World Energy* [4.1] is probably the most cited reference when it comes to a detailed description of oil consumption (it can be accessed via Internet free of charge). This document includes detailed figures for consumption of crude oil, shale oil, oil sands and NGLs (natural gas liquids – the liquid content of natural gas where this is recovered separately). For 2005, the total consumption of these products was reported to be 81.1 million barrels per day (Mbpd).

The IEA has another reporting praxis, which includes as part of the non-conventional fraction coal to liquids (CTL), etc. They also include "processing gains", i.e. the increase in the volume of end products compared with the volume entering the refineries, etc. The IEA reports a global consumption of 84.5 Mbpd for the year 2005.

4.1 Production forecasts based on the depletion model

In the publication, *The Peak and Decline of World Oil and Gas Production*, we divide the production of oil reported by BP into regular oil, heavy oil, deepwater, polar oil and NGL [1.1]. Figure 4.1 presents an updated version [4.2] of the one detailed in that article.

Figure 4.1. **Production of oil and gas liquids to year 2006** [4.2] **and production scenarios** as described in [1.1]

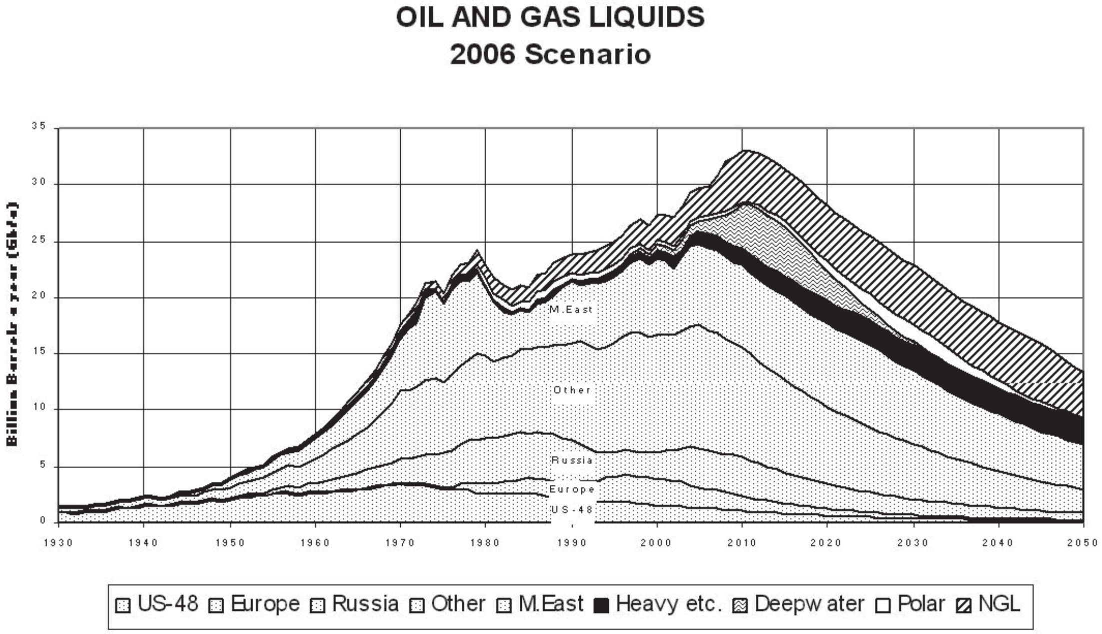


Figure 4.1 divides regular oil into the fractions US-48, Europe, Russia, Middle East and Rest of World. Future production of regular oil is considered country by country and then these results are combined to produce the graph. Separate studies are then made for each of the other fractions and combined with the data for regular oil. Future regular oil production is based on the fact that the reserves in a country can only be depleted within a certain percentage, the depletion rate.

With just the information for yearly production the change in production for a country can be expressed in terms of a decline rate, defined as the negative relative change of production over the year.

(Decline rate) = (Last year’s production – This year’s production)/(Last year’s production).

As oil reserves are not included in the decline rate, it is not suitable for scenarios of future production.

The depletion rate differs in that it takes into account the amount of oil that is left. It is defined as *this year’s production* divided by *the amount of oil that is left*.

(Depletion rate) = (This year's production)/(Oil left at start of this year).

Clearly, as more oil is produced, less oil is left. At a constant rate of production the depletion rate grows while the decline rate is zero. The depletion rate can never become negative.

Production for previous years gives the statistical trend for depletion, and new reserves are added based on previous updates and estimations of oil to be found in the country. The highest depletion rates are found in the North Sea and the smallest in the Middle East. The strength of this model is that it is based on the obvious fact that oil has to be found before it can be produced.

The updated forecasts presented in Figure 4.1 are given as updated numbers in Table 4.1 for regular, conventional oil and polar oil. Excluded from this data is production from bitumen, heavy oil, deepwater and Natural Gas Liquids.

Table 4.1. **Production of regular conventional oil for 2000 and 2005, as well as resource-based production forecasts for 2010, 2020 and 2030**

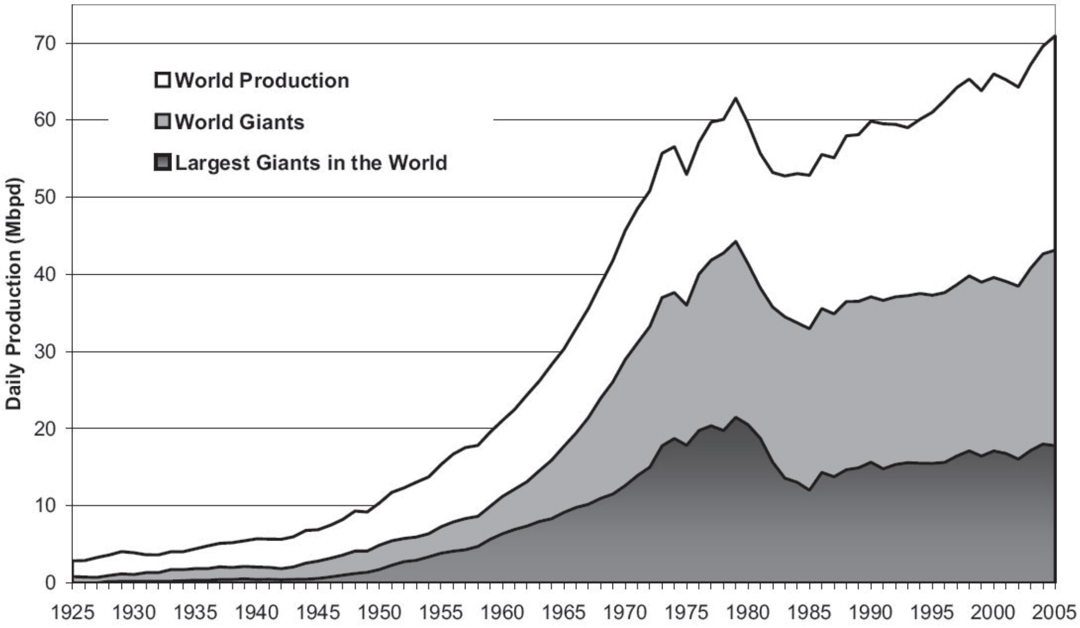
Production from bitumen, heavy oil, deepwater and Natural Gas Liquids are excluded

Region	**2000 MB/d**	**2005 MB/d**	**2010 MB/d**	**2020 MB/d**	**2030 MB/d**
Middle East Gulf region	*18.54*	*19.77*	19.86	20.23	17.80
Eurasia, including Russia	*11.27*	*15.32*	16.07	11.54	7.99
North America	*5.29*	*4.67*	3.72	2.11	1.21
Latin America	*8.43*	*7.97*	5.99	3.69	2.31
Africa	*6.77*	*7.87*	7.33	5.22	3.67
Europe	*6.53*	*5.26*	3.56	1.71	0.83
Asia-Pacific	*4.02*	*3.67*	3.19	2.11	1.38
Middle East minor	*2.91*	*2.85*	2.28	1.37	0.85
Other minor producer	*0.47*	*0.61*	0.53	0.38	0.28
Polar oil, Alaska	*1.0*	*0.8*	0.6	0.4	0.3
World total regular oil	***65***	***69***	**63**	**49**	**37**
Middle East Gulf Share	*28%*	*29%*	31%	41%	49%

4.2 Production from giant oilfields

Section 3.3, "Discovery of crude oil", discussed giant oilfields, i.e. those fields that will ultimately produce more then 500 million barrels (Mb) of oil, separately. In the UHDSG-Giant Oilfield Database (UHDSG-GOD [1.6]) we have collected all data on the production from giant fields, and Figure 4.2 illustrates their share of production.

Figure 4.2. **World oil production, excluding condensate and NGLs**
in million barrels per day (Mbpd),
and the contribution from 312 giant fields and 21 fields with production exceeding 0.1 Mbpd for at least one year. In addition, the contribution from the largest fields is included [1.6].



The disadvantage with the country-by-country depletion model is that the summing of country predictions also incorporates the uncertainty of individual forecasts. If the primary interest is to construct a global forecast, it is much better to divide the production into the following fractions:

- Giant oilfields;
- Small oilfields;
- Deepwater oilfields;
- New field developments;
- Oil sand production;
- Heavy oil – Orinoco Belt;
- Natural gas liquids.

The open data for giant oilfields gives conflicting values for their URR, and subsequently the best way to use these numbers is to treat them as upper and lower limits. Table 4.2 presents the data for the 20 largest oil fields in the world.

Table 4.2. **The 20 largest oil fields in the World with respect to URR [1.6]**

Field name	Country	Discovery year	Production start	Range of URR (Gb)
Ghawar	Saudi Arabia	1948	1951	66-150
Greater Burgan	Kuwait	1938	1945	32-75
Safaniya	Saudi Arabia	1951	1957	21-55
Rumaila	N. & S. Iraq	1953	1955	19-30
Bolivar Coastal	Venezuela	1917	1917	14-30
Samotlor	Russia	1961	1964	28
Kirkuk	Iraq	1927	1934	15-25
Berri	Saudi Arabia	1964	1967	10-25
Manifa	Saudi Arabia	1957	1964	11-23
Shaybah	Saudi Arabia	1968	1968	7-22
Zakum	Abu Dhabi	1964	1967	17-21
Cantarell	Mexico	1976	1979	11-20
Zuluf	Saudi Arabia	1965	1973	11-20
Abqaiq	Saudi Arabia	1941	1946	13-19
East Baghdad	Iraq	1979	1989	11-19
Daqing	China	1959	1962	13-18
Romashkino	Russia	1948	1949	17
Khurais	Saudi Arabia	1957	1963	13-19
Ahwaz	Iran	1958	1959	13-15
Gashsaran	Iran	1928	1939	12-14

An oil company with detailed field information can make sophisticated predictions about future oil production. In late 2005 the state-owned Mexican oil company, Pemex, made an internal forecast for the giant oilfield, Cantarell. They presented a "best case" and a "worst case" scenario. Cantarell, the second largest oilfield in the world when it comes to production, produced 2 Mbpd in December 2005. According to the "best case" scenario, production was predicted to be 1.9 Mbpd over the next year, with the "worst case" scenario predicting 1.6 Mbpd. The two different scenarios were based on varying estimates of URR. The actual production turned out to be 1.5 Mbpd [4.3].

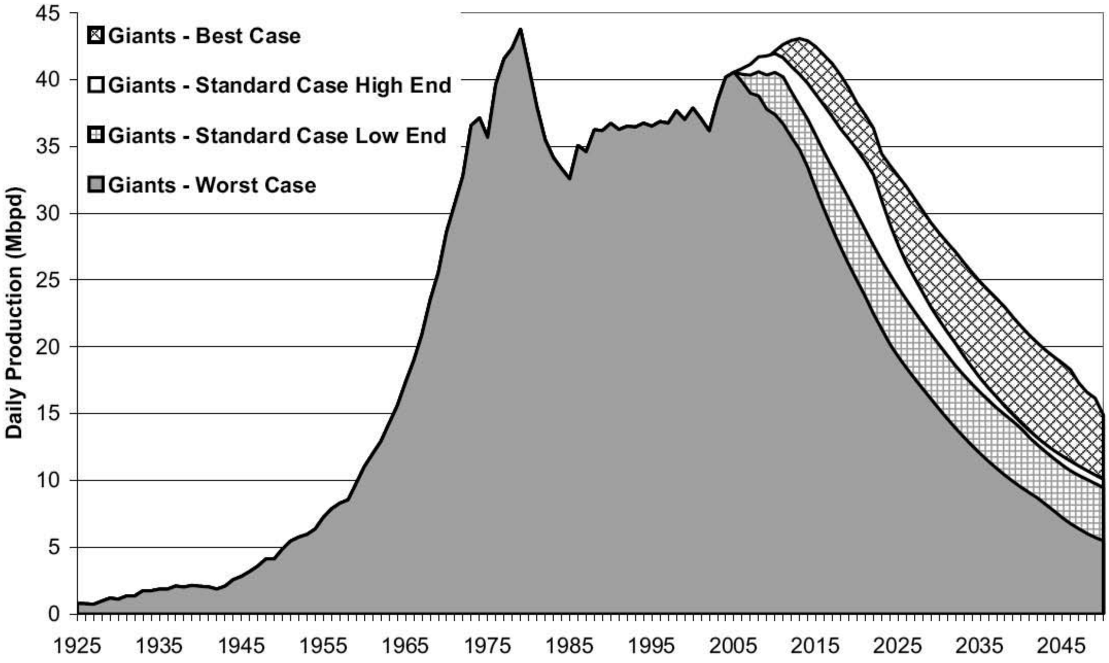
Uppsala Hydrocarbon Depletion Study Group has developed a model to predict future production from giant oil fields [1.6]. A general model is applied along with a number of outcomes dependent upon the stated upper and lower limits for the URR (another important parameter is the decline parameter for giant oilfields). Data from the Cantarell scenarios supports such an approach. Different future production conditions will be simulated and the range between the various outcomes can serve as an error estimate.

Production from a giant oilfield follows a very specific pattern. Past production includes a start-up period and an early plateau in production based upon installed production facilities. There is then a late production plateau followed by declining production. Summing the three phases should yield the applied URR. Analyses of 20 giant fields gives decline rates of between 6 and 16% and three different rates (6, 10 and 16%) are used for different scenarios.

The results of this analysis produced four different possible scenarios. "Worst Case" and "Best Case" as the limits, but the more realistic scenarios are designated the "Standard Case Low End" and

“Standard Case High End”. The four scenarios for production from giant oilfields are presented in Figure 4.3.

Figure 4.3. **Future oil production from giant oilfields**
million barrels per day, Mbpd [1.6].



The fact that most of the oil in giant oilfields was found between the years 1940 and 1980 (a forty-year period) means that the bulk of their production will go into decline during a rather short time frame, and the high decline rates for giant oilfields will mark the beginning of the end of production.

4.3. Production from small oilfields

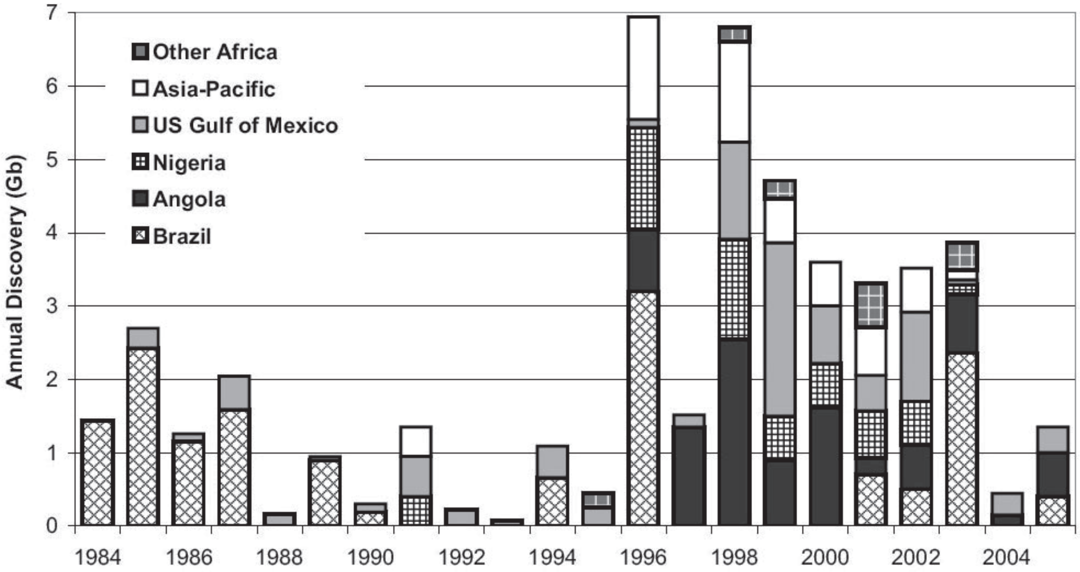
The total production from existing oilfields is declining. As an example, Exxon Mobile provides a range of 4 to 6% in their publication, *A Report on Energy Trends, Greenhouse Gas Emissions and Alternative Energy* [4.4]. As the giant oilfields tend to have high decline rates we apply only a 3% decline in the production from existing small oilfields.

4.4. Production from deepwater oilfields

The development of offshore technology for exploration and production of petroleum is a true landmark in technological development. The first 94 offshore drilling projects took place in waters of a depth of 11 metres in Summerland, California in 1897 and currently typical water depth is around 1 000 metres.

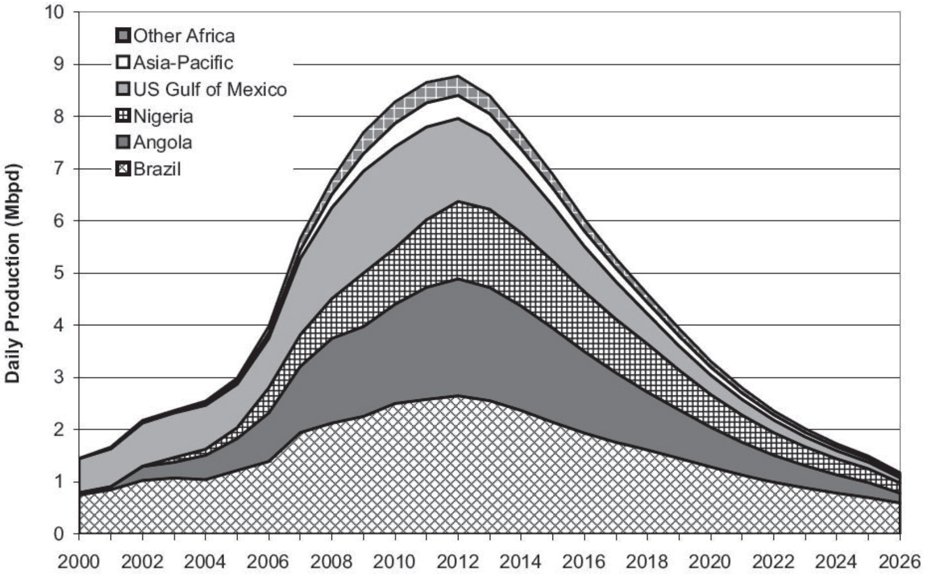
Exploration in deepwater (waters exceeding 500m deep) has so far been conducted primarily in three regions that hold the most discovered resources: the US Gulf of Mexico, Brazil and West Africa. Figure 4.4 shows the annual deepwater discoveries and further illustrates that exploration really took off in the mid-1980s, mainly due to advances in seismic reflection imaging, which led to a reduction in the geological risk involved in deepwater exploration. Data for deepwater oilfields has been collected in a database [1.6] and this database has been used to determine production forecasts from these deep water oilfields (see Figure 4.5).

Figure 4.4. **Annual deepwater discoveries**
billion barrels per year [1.6]



The peak in discoveries at the end of the 1990s is reflected as a peak in production, with 8.8 Mbpd around 2012. Even though new discoveries can make the decrease in production less steep, we cannot expect this production to offset the decline in production of existing oilfields.

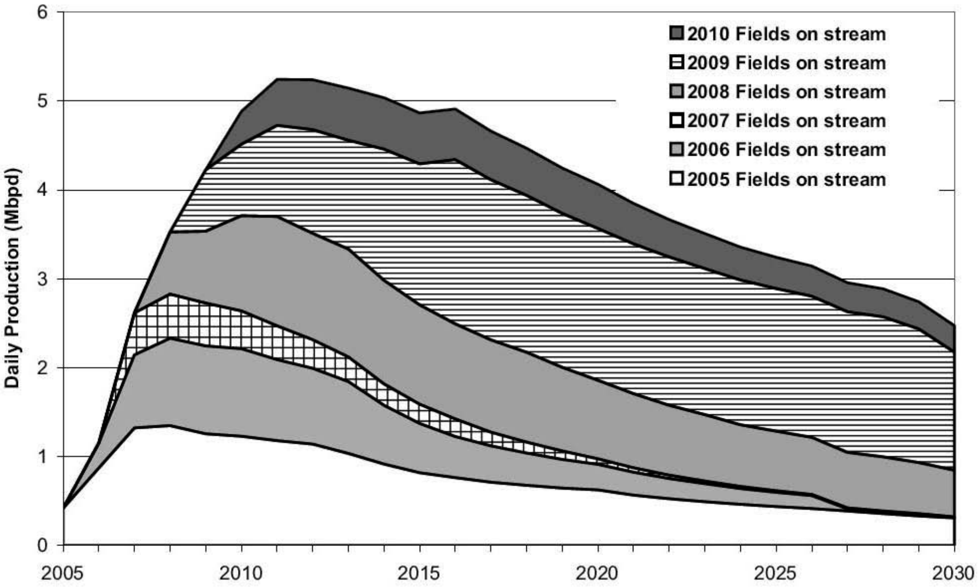
Figure 4.5. **Deepwater production forecast**
million barrels per day [1.6]



4.5. Production from developments of new oilfields

The future development of oil fields is an essential part of future oil production. Those fields will help to fill the gap between old declining fields and rising demand. The forecast for future production from new field developments includes all major developments but excludes deepwater projects (Figure 4.6). Our database covers over 80 fields that came on stream during 2005 or will come on stream as late as 2013. In addition, some field extensions in non-giant fields that came on stream prior to 2005 are included (for details, see Appendix B in reference 1.6).

Figure 4.6. **Production forecast for new field developments**
million barrels per day (Mbpd)

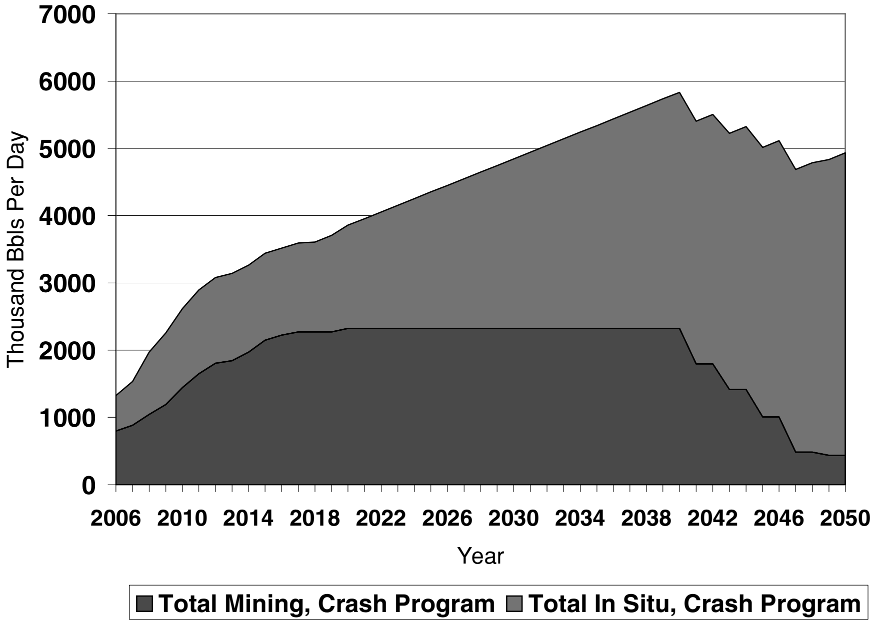


4.6. Production from oil sand in Canada

The province of Alberta in the south-western part of Canada holds the entire resource base of Canadian oil sands, and UHDSG has made a "Crash Program Scenario for the Canadian Oil Sand Industry" [1.5]. Typically, oil sand is assembled in porous rocks and consists of up to 80% sand, silt and clay. The actual resource extracted from oil sands is bitumen, which in turn goes through further processing to produce a synthetic crude oil (SCO) suitable for conventional refineries.

There are two main technologies for extracting bitumen from oil sands: open mining and *in situ* thermal production. Open mining requires the removal of an overburden in order to reach the oil sands. Some 20% of the reserves, 35.2 Gb, are deposits shallow enough to be mined.

Figure 4.7. **Oil production from Canadian oil sand**
million barrels per day from mining and *in situ* production [1.5]

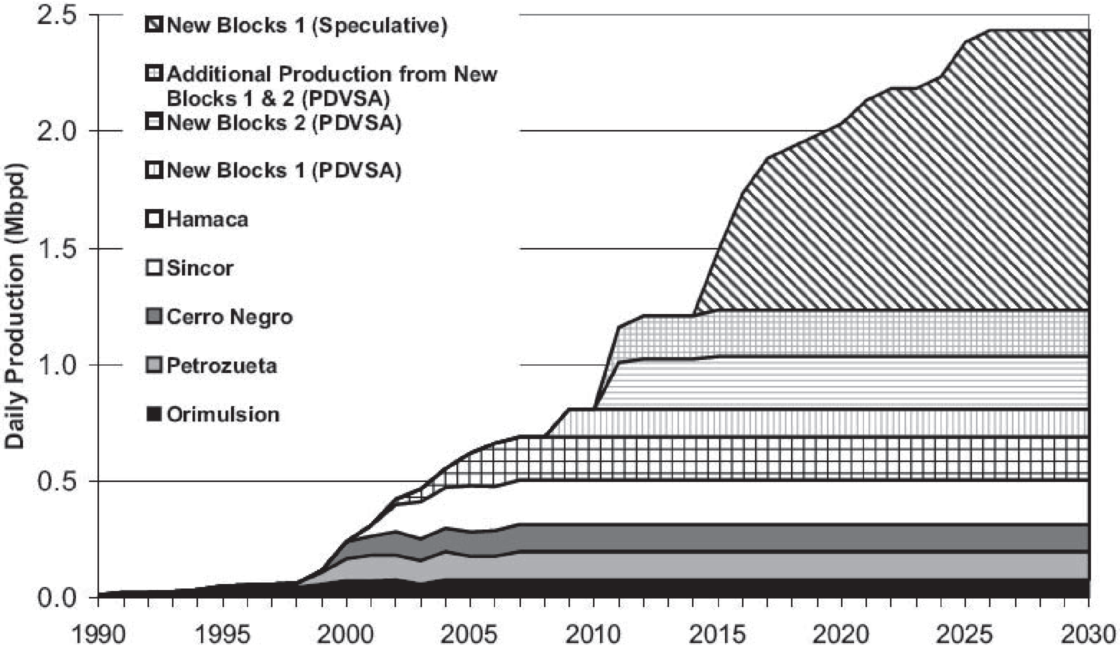


When the overburden is too thick for strip mining, *in situ* extraction methods have to be applied, and the different thermal methods applied have been described in our existing work. One big hurdle in the expansion of *in situ* production is the need for natural gas. As an industry rule of thumb, it takes 1 000 cubic feet of natural gas to produce one barrel of bitumen. In addition, some 400 cubic feet of gas are needed to upgrade one barrel of bitumen to one barrel of SCO [1.5]. Thus, 1 400 cubic feet of natural gas is required to convert bitumen to one barrel of SCO. The remaining established *in situ* reserves are 142.2 Gb. Production for the two scenarios is presented in Figure 4.7, and for the year 2030 we have a maximum production of 5 Mbpd, but this high production needs nuclear power to produce steam.

4.7. Production of heavy oil from the Orinoco Belt in Venezuela

The estimated oil in place in the Orinoco heavy oil belt is 1 360 Gb and the latest recovery estimate approaches 20%, which gives a reserve of 236 Gb. The development of horizontal drilling techniques and the increased cost effectiveness of both drilling and pumps has made it possible to recover the heavy oil without using costly thermal methods. However, even with these advances in technology thermal methods are still used to a certain extent.

Figure 4.8. **Production from the Orinoco Belt, both historic and a forecast up to 2030**
million barrels per day (Mbpd)



Note: Only Hamaca, Cerro Negro, Petrozueta and Sincor are actually in production [1.6].

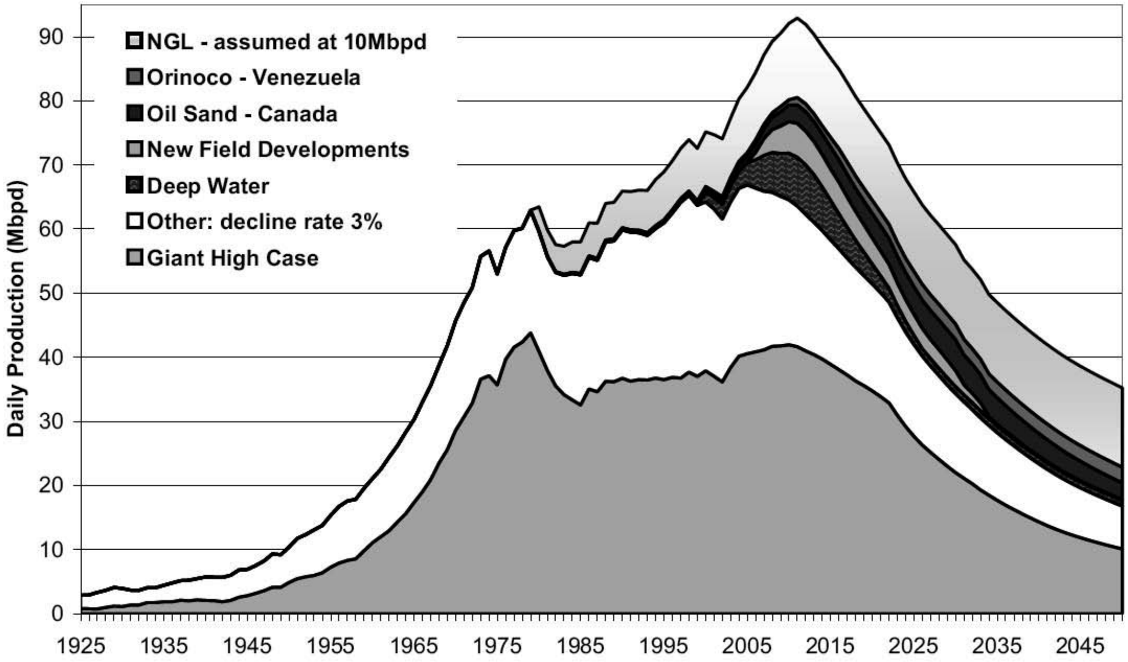
The production profile for the Orinoco fields is to ramp up to a plateau and then maintain this production plateau for a long period of time. The aim for the four main projects in Orinoco is to keep the level at 0.6 Mbpd for 35 years. This level is used as the base for the forecast of future Orinoco production (Figure 4.8). From 2009, a new block will add a production of 0.12 Mbpd and in 2010 a further new block plus additional production from the first new block will add an extra 0.35 Mbpd. This leaves a total production, including an assumed orimulsion production, of 0.10 Mbpd and of 1.2 Mbpd in 2012 [1.6].

However, since the resource base is large it is assumed an extra expansion starting in 2015 will eventually reach 1 Mbpd by 2020. As this expansion continues, total production will reach 2.4 Mbpd by 2025.

4.8 Final production profile and conclusions

The aim of the giant oilfield study was to examine the dominant influence on production from giant oilfields, so rather than trying to make a detailed analysis of the Natural Gas Liquid fraction, we have simply assumed that today's production will remain constant. In Figure 4.9 we have added all the different liquid streams for the Giant High Case scenario.

Figure 4.9. **Global liquids production per liquid stream for the Giant High Case**
million barrels per day (Mbpd) [1.6]



This scenario allows for an increase in production over successive years at a rate greater than the 1.4% that the IEA use in their demand forecast, but there is no way that we can see a production of 115 Mbpd by 2030. Peak oil for this scenario will occur around the year 2012.

If we now adjust the forecast scenarios to an increase in demand of 1.4%, the peak in oil production will be delayed and the upper limit for peak oil will be 2018, and this is for the best case scenario (see Figure 4.10).

However, we believe that the high case scenario is unlikely to happen, as it requires the 10 giant oilfields described in Table 4.3 to come into production shortly. Seven of these fields can be found in Iraq and investments in these oilfields require political and economic stability in that country.

Figure 4.10. **Global liquids production for all scenarios**, **with the best case scenario adjusted to fit an annual demand growth of 1.4%,** million barrels per day (Mbpd)

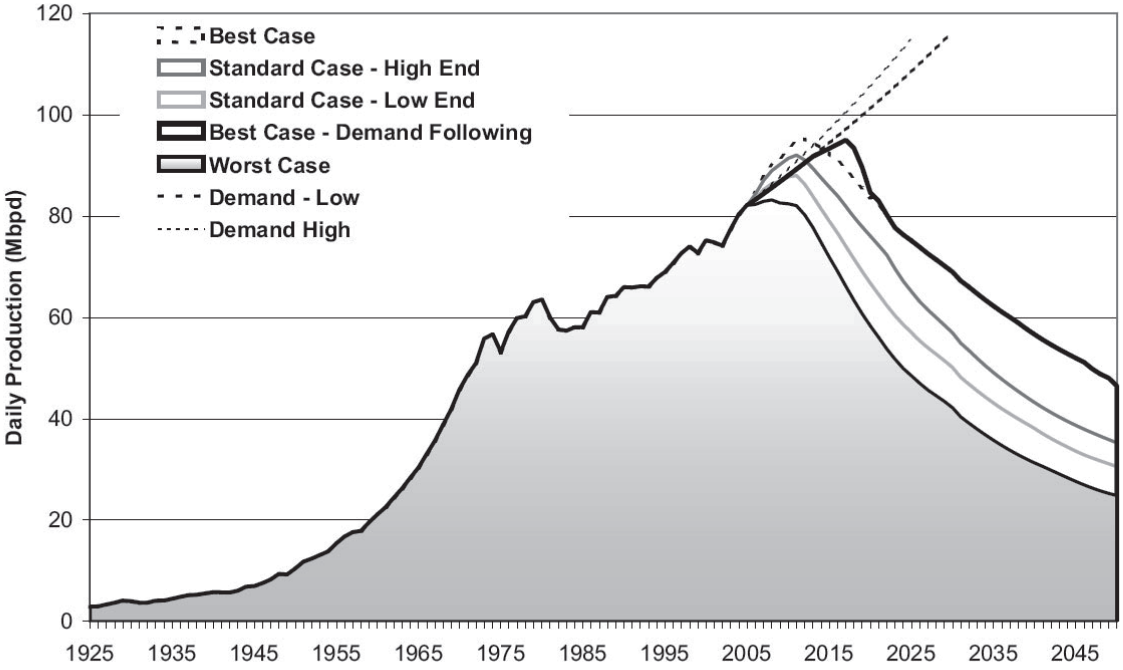


Table 9.3. **Major field expansions included in the best case scenario,** [thousand barrels per day (kbpd)]
Field production is assumed to increase gradually.

Field	**Country**	**Peak level**	**Year of peak (kbpd)**	**Comments**
Tengiz	Kazakhstan	825	2012	
Northern fields	Kuwait	900	2013	Much delayed project
Majnoon	Iraq	1000	2018	Gradual expansion
West Qurnah	Iraq	550	2015	
Halfayah	Iraq	250	2014	Re-development of old field
Nahr-Umr	Iraq	500	2017	Re-development of old field
Nasiryah	Iraq	300	2016	Re-development of old field
Zakum Upper	Abu Dhabi	700	2013	Low pressure, poor porosity
Ratawi	Iraq	200	2013	Re-development of old field
Tuba	Iraq	180	2015	Re-development of old field

4.9 Conclusions for production

Production of future oil has been studied with the "depletion model" and with the "giant field model". Both models give us a peak in the production of oil in the vicinity of the year 2012. The giant low-case scenario indicates that we have now just reached a plateau in production that will remain constant for 5 to 7 years and that we will then witness a steady decline.

Another interesting observation is that both models predict production of between 50-60 Mbpd for the year 2030. The giant field study can explain this by observing that giant oilfields are already declining rapidly and that more than 50% of current oil production is in the giant fields. Therefore our demand forecast of 101 Mbpd in 2030 (see Section 2.2) cannot be fulfilled.

4.10 References

[4.1] *The BP Statistical Review of World Energy*, www.bp.com

[4.2] Colin Campbell, ASPO Newsletter 81, http://www.aspo-ireland.org/contentFiles/newsletterPDFs/newsletter81_200709.pdf

[4.3] David Luhnow, Dying Giant - Mexico Tries to Save A Big, Fading Oil Field, *Wall Street Journal*, April 5 (2007), p. A1.

[4.4] Exxon Mobil, *A Report on Energy Trends, Greenhouse Gas Emissions and Alternative Energy*, February 2004.

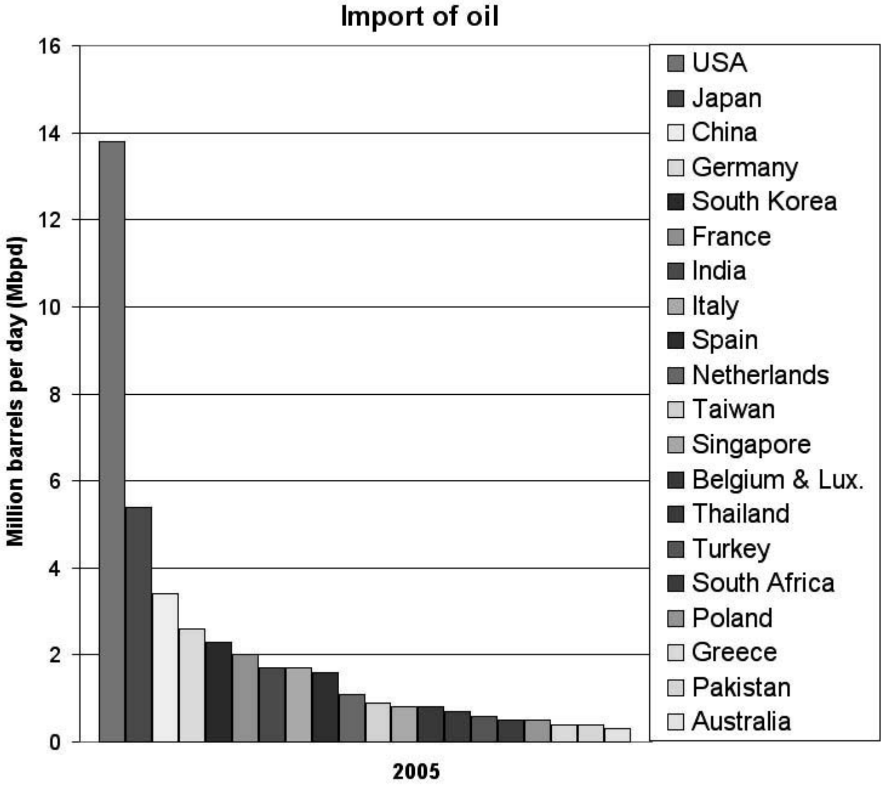
5. IMPORT AND EXPORT SCENARIOS

Over the years it has been hard to convince politicians, economists, etc., that peak oil is a fact of life and not just a theory. When it comes to describing peak oil, theoretical methods are used and in this work we have discussed the "depletion model" and the "giant field model". A breakthrough in convincing the individual about peak oil occurs as we begin to discuss the import and export of oil. So far there has been no other opinion than **"the import of oil requires that someone else is willing to export oil".** The "Peak Oil Moment" arrives and peak oil becomes reality.

5.1 Importing and exporting countries

From the annual figures for oil production/consumption published in the *BP Statistical Review of World Energy* [5.1], we can determine which countries are net importers and which are net exporters. In 2005, oil exports were 48 million barrels per day, with 29% of global crude oil exports going to the US and with Japan and China in second and third place (11% and 7% of global exports, respectively).

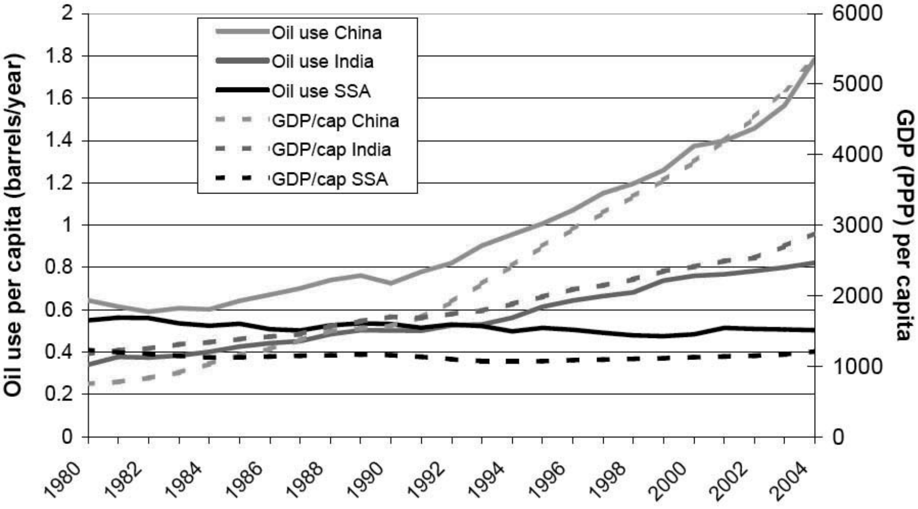
Figure 5.1. **Net imports of crude oil for the twenty largest importers [1.4]**



Clearly, those nations that require imported oil must find countries that are prepared to export oil, and to date this has been possible, with the exception of the 1970s and 1980s when the flow of oil was constricted in the Middle East. Normally the transfer of oil into one country will come from several different sources. Examining all exports, we find that Saudi Arabia is the number one exporter, with a volume of just over 9 Mbpd, Russia is number two with 6.8 Mbpd and Norway comes third with 2.8 Mbpd. Exports from Norway, a member of the OECD, are now in decline.

During the last thirty years, the annual increase in average Gross Domestic Product (GDP) globally has been 3% per year compared with an average increase in oil consumption of 1.6% per year [5.2]. In developing countries, the correlation between GDP and oil consumption is stronger than average. The correlation for China, India and SSA (sub-Sahara Africa) for the time period 1980 to 2004 is given in Figure 5.2. The Sub-Sahara Africa region shows no increase in oil consumption per capita and this correlates with a zero increase in GDP per capita for the region [1.7].

Figure 5.2. **Development of GDP (PPP) and oil use per capita in China, India and SSA, 1980-2004**



In WEO 2006, the IEA forecast that the increase in oil consumption would be 1.4% per year for the next 25 years, requiring that oil production reach 115 Mbpd by 2030 [2.6]. The US EIA forecasts a production of 118 Mbpd for the same year [2.7]. Compared with today's production of 85 Mbpd, an increase of 30 Mbpd in global production will be required to reach the forecasts of the IEA and the EIA [1.4].

According to the EIA, US consumption will increase by 6.2 Mbpd (30%) by 2030. As production is projected to stay constant, all of this increase must come from new imports of oil, meaning imports will increase from 13.8 Mbpd (2005 numbers) to 20.0 Mbpd – an increase of 45%.

China is consuming 7.4 Mbpd and imports reached 3.8 Mbpd in 2006. Over the last five years, consumption has increased by an average of 9% per year. Production within China is 3.7 Mbpd today and is expected to decline through to 2030. What future increase in oil demand will we see in China? A 9% increase would give an unrealistic 54 Mbpd, twice as much as the USA. But a 5% increase will put China and the USA on the same level, with an import requirement in the order of 20 Mbpd.

The rest of the importing countries import 31 Mbpd, and a modest increase of 1% per year will give an additional 10 Mbpd in import demand, producing a combined import requirement in the order of 80 Mbpd or an increase in the order of 30 Mbpd. Can those countries exporting oil deliver?

Saudi Arabia is the largest oil exporter in the world and no-one denies that this primacy will be assailed. When there is any discussion of future Saudi oil production, it is normally the business of the oil minister. An exception to this was in February 2004, when Mahmoud M. Abdul Baqi and Nansen G. Saleri reported data from the state oil company, Saudi Aramco [5.3]. The production scenarios presented were labelled Maximum Sustainable Capacity (MSC). Today, the MSC is 10 Mbpd and it is proposed this could be maintained until 2042. Another scenario increases production to 12 Mbpd, maintaining the MSC until 2033. The basis for these scenarios is that the Saudi reserves are 260 Gb and, as pointed out in 2.2, this is a highly questionable figure.

Figure 5.3. **Net export of crude oil for the twenty largest exporters** [1.4]

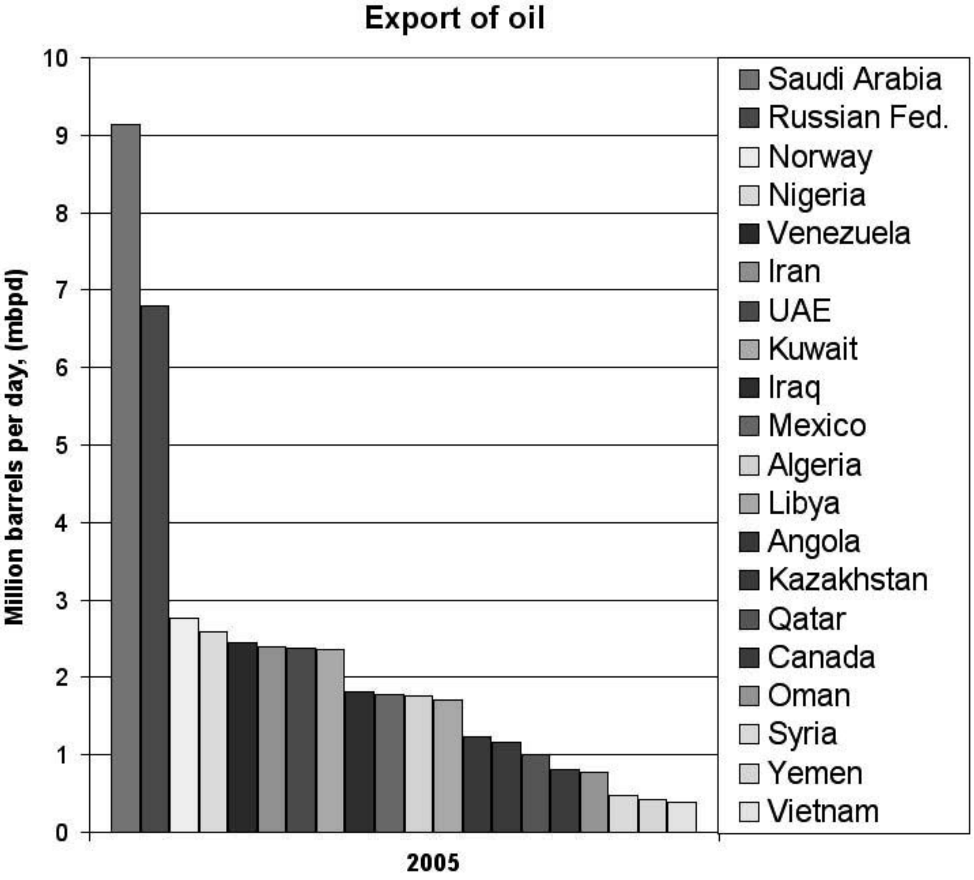
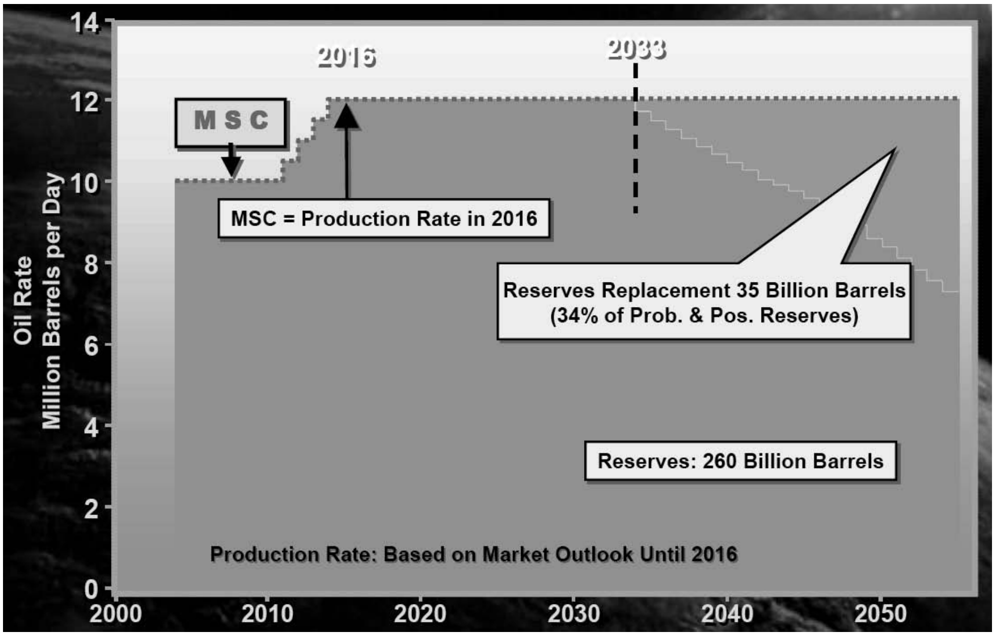


Figure 5.4. **The Saudi Aramco Maximum Sustainable Capacity Production Scenario [7.4]**

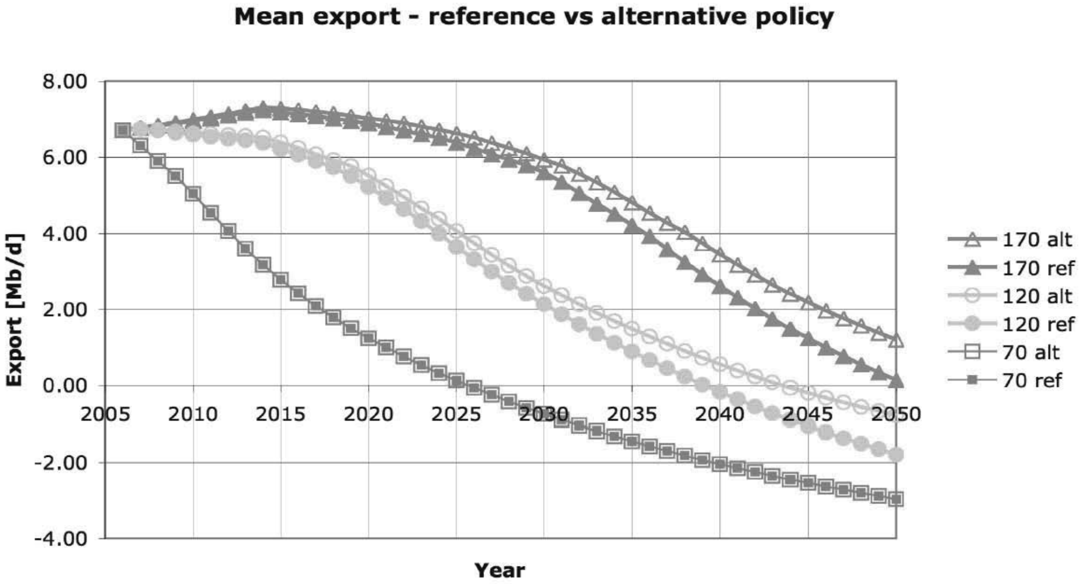


When trying to determine possible future exports, the growing Saudi population must be taken into account, as more of Saudi's oil will be needed for domestic use. Consumption now stands at 2.0 Mbpd, with an average increase over the last 25 years of 5% per year. It will be very hard for Saudi Arabia to put any restrictions on this domestic consumption, and an increase of 5% per year in the coming years will increase consumption to 4 Mbpd. The planned production increases reported will be needed within the country, and therefore we cannot expect ever-increasing exports from Saudi Arabia.

In early June 2006, the Russian Ministry of Economics announced that Russia would reach a maximum production of 9.85 million b/d in 2009. By accepting this number as a plateau, it is possible to predict future production from the oilfields in Russia, if URR is known. An alternative method could be to assume that Russia can increase its production by 2 Mbpd, the same amount that Saudi Arabia claims to be possible.

There are different opinions about possible future Russian URR grouped around the figures 70, 120 and 170 Gb. Today, BP lists the number 79 Gb. With a modest increase in domestic use and depletion rates within acceptable values, we have made predictions on future export capacity for Russia (see Figure 5.5). The 70 Gb scenario appears pessimistic, the 170 Gb over-optimistic, leaving the 120 Gb scenario as the probable best case. The best case gives exports of between 2 and 3 Mbpd for 2030 depending upon consumption within Russia [1.9].

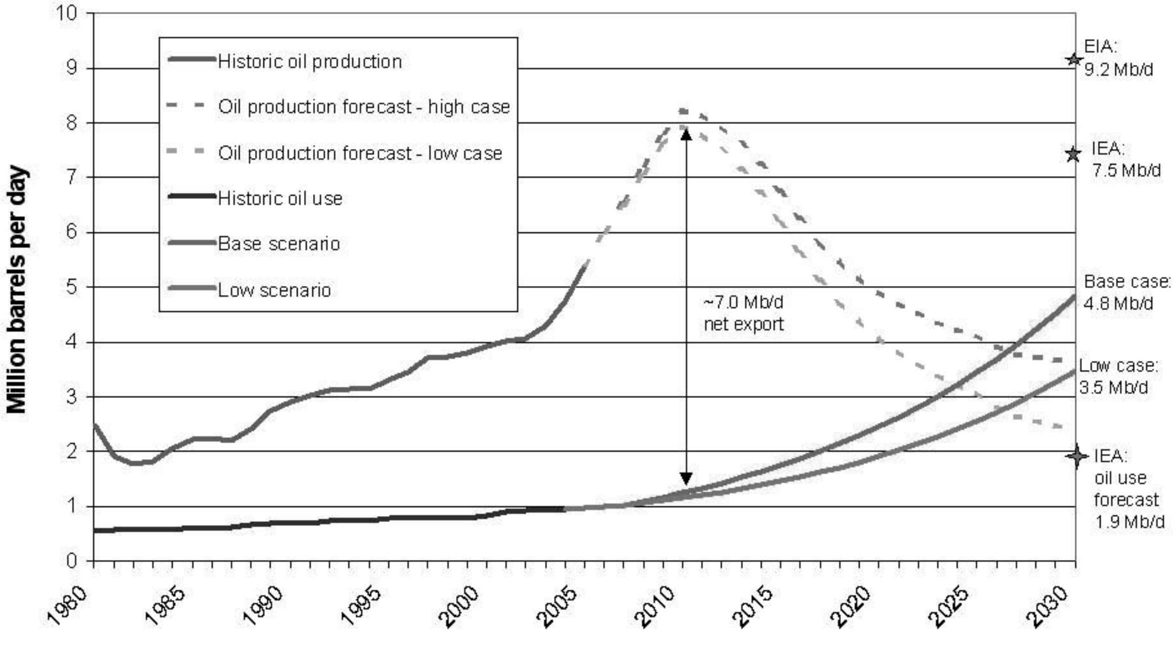
Figure 5.5. **Mean export comparison between the reference policy and the alternative policy for Russia, with respectively 70, 120 and 170 Gb left to produce** [1.7]



Norway, the number three exporter today, states that in 2030 its maximum production will be 500 000 b/d, with a possible minimum of 200 000 b/d. Exports for 2005 of 2.8 million b/d will therefore decline by more than 2 million b/d by 2030.

Mexico is yet another exporter that will lose a big fraction of its export capacity if new fields are not discovered and massive additional production developed. We know that production from Cantarell is falling like a rock.

Figure X. **Scenarios of total oil use versus projected oil production in SSA**



The SSA region has been studied in detail [1.7] and it is obvious that an increase in GDP requires a proportional increase in the consumption of oil. The necessary oil is produced within the region, but OECD countries and China are taking the oil away from where it is needed. Over the next five years, Angola and Nigeria will increase production by 3 million b/d, but by 2030, production in these two countries will have declined back to current levels [1.7]. The IEA expects an increase in exports from the region by 2030 of 1 Mbpd, but in reality we can expect a decline. If the IEA oil use forecast for the region is accepted, the decline will be 2 Mbpd.

To avoid any more clouds on this stark horizon, just assuming that other Middle East countries can keep their export volumes constant – which is a very optimistic assumption – and allowing the Caspian region an export increase of 2 Mbpd, we conclude that there will be a decline in export volumes by 2030. Anyone who claims something different must explain in detail what is wrong with this analysis.

5.2. References

[5.1] *BP Statistical Review of World Energy* (www.bp.com).

[5.2] International Energy Agency, *World Energy Outlook 2004*; http://www.iea.org/textbase/nppdf/free/2004/weo2004.pdf

[5.3] Mahmoud M. Abdul Baqi and Nansen G. Saleri, *Fifty-Year Crude Oil Supply Scenarios: Saudi Aramco’s Perspective*, February 24, 2004, C, Washington, DC, http://www.csis.org/media/csis/events/040224_baqiandsaleri.pdf

6. PRODUCTION OF TRANSPORT LIQUIDS WITH CTL AND GTL

Coal-to-Liquids (CTL) and Gas-to-Liquids (GTL) are fuels that can be produced from coal, natural gas and biomass using the Fischer-Tropsch process. The liquids produced include naphtha, diesel and a variety of chemical feedstocks. The resulting diesel can be used neat or blended with today's diesel fuel and used in existing diesel engines and infrastructure. In mitigation studies [6.1], these fuels are discussed as an opportunity to reduce dependence on petroleum-based fuels, but can they perform this function in reality?

6.1 CTL production

The USA and China are now importing more than 50% of their oil requirements, and this reality has opened a debate about the use of coal reserves for the production of liquid fuels. The Fischer-Tropsch method was developed in Germany during the Second World War and used in South Africa during the period of apartheid and international sanctions, when they were cut off from imports of oil. Economically, it has been much more expensive than pumping oil from the ground, and the fact remains that this technique has only been used to secure liquid fuels when a country is in a state of emergency. The fact that this method is now discussed might indicate that the world is entering just such a state of emergency.

The Coal-to-Liquids Coalition (CTLC) in the USA is using energy security as a motivation for the further development of CTL production [6.2]: "*Establishing a goal of producing at least 300 000 barrels of high-grade fuel per day by 2015 using CTL technology is a feasible target. This is equivalent to the amount of transportation fuel consumed daily by the US military for domestic operations.*"

In China, oil security is also on the agenda and at the ASPO-6 Conference, Professor Pang (Vice-Chancellor of the China University of Petroleum in Beijing) pointed out that the security goal for China was to have a self-sufficiency ratio (self-produced-oil/oil-consumption) of more than 50% [6.3]. CTL is part of this equation.

Figure 6.1. **Coal production forecast for China**
The peak is even more imminent if the reserves are backdated to 1992 when the last actual updates took place [1.10].

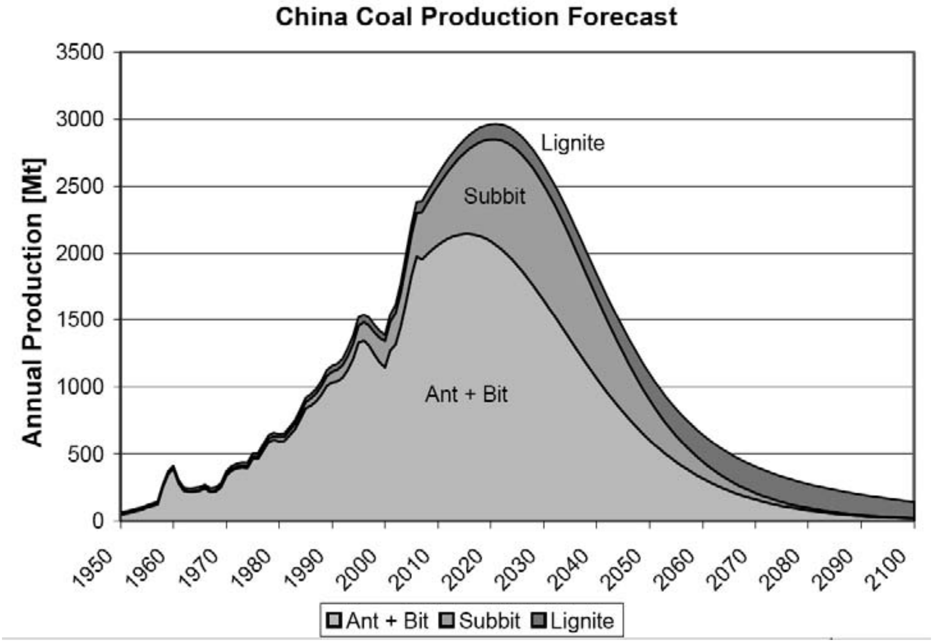
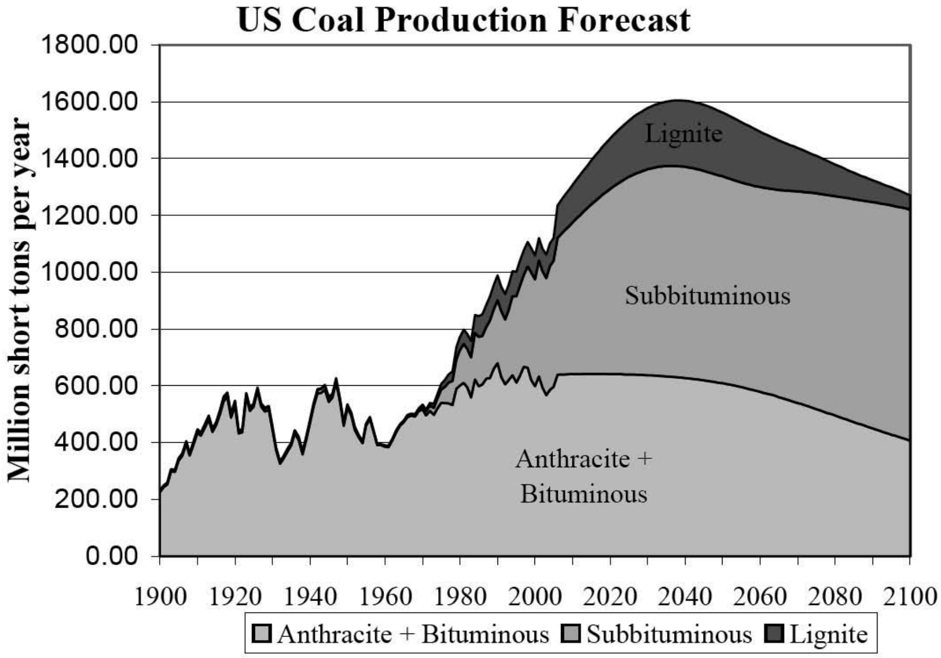


Figure 6.2. **Forecasted coal production based on EIA data on the recoverable reserves and adapted to historical production**



The continued rapid expansion of coal production from Wyoming peaks in 2030 and is followed by a decline, dampened by sub-bituminous coal from Montana. No major increase in bituminous coal production is possible due to a lack of available reserves. It will also be impossible to reach the EIA forecast for 2030 [1.10].

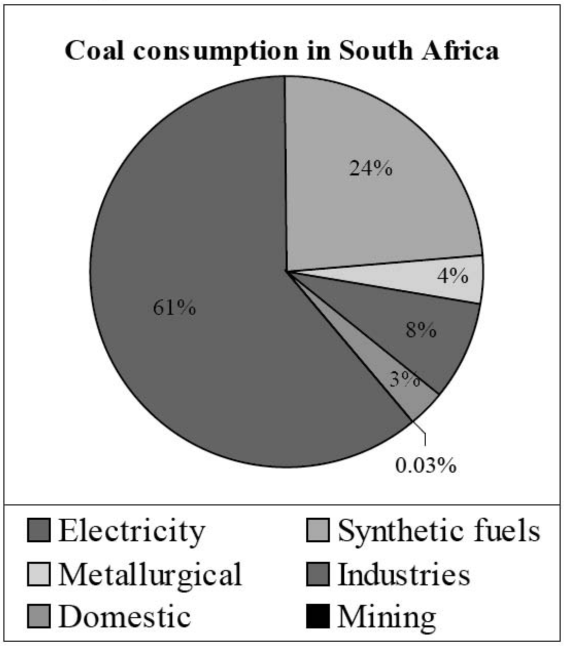
The Uppsala University Hydrocarbon Depletion Study Group has, in collaboration with other researchers, made "A resource-driven forecast for future global coal production" [1.10], and we have found that both China and the USA will face a "Coal Peak" before 2050 (Figures 6.1 and 6.2), and furthermore there will be increased competition between coal for electricity and CTL production.

Table 6.1. Top five coal producers, 2006 [1.10]

Country	Production (Mt)	Share of world
China	2 380	38.4%
USA	1 054	17.0%
India	447	7.2%
Australia	374	6.0%
Russia	309	4.9%
South Africa	240	3.8%

South Africa has a large CTL industry, producing approximately 30% of its fuel needs by Fischer-Tropsch synthesis. This takes place at the Sasol CTL complex at Secunda, which has a production capacity of 150 000 barrels per day. As seen in Figure 6.3, this utilizes a significant share of the country's coal production, and from Table 6.1 we can conclude that this represents 0.9% of global coal production.

Figure 6.3. **South African coal consumption divided into groups** [1.10]



The decline in production from existing oilfields is said to be between 4 and 6%. In absolute terms, this means that one year from now new production in the order of 4 Mbpd must come on stream to compensate for the decline. A modern CTL factory might yield 0.2 Mbpd and therefore 20 factories could produce the annual decline of 4 Mbpd. With the numbers taken from South Africa, it can be seen that this development of CTL production represents a total requirement of coal that is 60% of Chinese production, or 60% more than current production within the USA. Compared with global production, we calculate that 4 Mbpd synthetic diesel needs 25% of the production. New facilities might be more efficient but even a 50% increase in production efficiency will still draw a substantial fraction of global coal production.

A massive investment in CTL cannot solve the problem in global oil decline. The 300 000 barrels per day that the American military needs in the future may be attained.

6.2. GTL production

The gas-to-liquid (GTL) process requires large volumes of low-cost natural gas to compete with diesel fuel in the open market. GTL produced from pipeline-supplied natural gas would not be competitive, due to the higher alternative value of pipeline natural gas in the EU and the USA.

Natural gas is more expensive to transport on ships than oil, and converting remote natural gas into a liquid before transportation is discussed as a more cost-effective method. Since the late 1990s, major oil companies, including ARCO, BP, Conoco Phillips, Exxon Mobil, Statoil, Sasol, Sasol Chevron, Shell and Texaco, have announced plans to build GTL plants to produce liquid fuels, but today we can see that only a few of these projects may actually reach production. Millions of barrels will never be produced in the time frame 2008 to 2030.

6.3 References

[6.1] Hirsch, R.L., R. Bezdek, R. Wendling, Peaking of World Oil Production: Impacts, Mitigation & Risk Management, DOE NETL, February 2005. http://www.pppl.gov/polImage.cfm?doc_Id=44&size_code=Doc

[6.2] Home page for the Coal-to-Liquids Coalition (CTLC) in USA; http://www.futurecoalfuels.org/security.asp

[6.3] Pang Xiongqi, Feng Lianyong, Zhao Lin, Tang Xu, Li Junchen, Meng Qingyang, China University of Petroleum, Beijing, ASPO-6, http://www.aspo-ireland.org/index.cfm?page=aspo6

7. POSSIBLE STRATEGIES OF OIL IMPORTING AND EXPORTING COUNTRIES

At the time of writing, the price of oil has passed $80 per barrel and has remained above this landmark price for some time. When the Association for the Study of Peak Oil & Gas (ASPO) was founded in 2001, most authorities on oil held the belief that the future price of oil would not pass $30 per barrel, Table 7.1. When I wrote at that time about peak oil in a number of Swedish newspapers, my ideas were considered to be crazy, as "Actual forecasts from repayable official and private actors showed no sign of increase [6.1]." At that time, it was forecast that a price of $80 per barrel in 2010 would be an indicator of peak oil. Today, major players still deny peak oil, even though we have now seen sustained high oil prices.

Table 7.1. **Oil price predictions by agencies and market analysts at the beginning of 2001, in $ per barrel**

	2010	**2020**
International Energy Agency, IEA	20	27
US Department of Energy, EIA	21	22
European Commission	20	24
Canada Department of Energy	21	21
Standard & Poor	17	20
Deutsche Bank	18	18

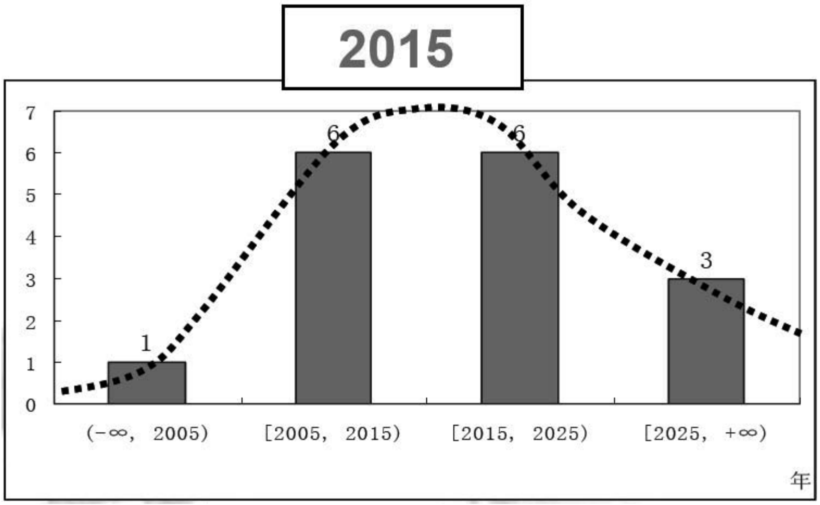
When it comes to considering import strategies, we must start by examining the USA. Of the 20.6 Mbpd the USA consumes, they have a self-sufficiency ratio of 33%. The reality of this is that at least one supertanker must arrive at a US port every four hours. Any interruption in this pattern is a threat to the American economy. The fact that imports from the Middle East are crucial has inexorably led to a policy requiring a prolonged military presence in the region. The statement "I am saddened that it is politically inconvenient to acknowledge what everyone knows: the Iraq war is largely about oil", from the memoirs of the former Federal Reserve Chairman, Alan Greenspan, lends supports to this position. It should also be noted that President Bush has told the American people that military bases in Iraq will be needed for the foreseeable future. Furthermore, UHDSG has concluded that even a best-case scenario requires that seven giant oilfields in Iraq must be brought on-stream soon [1.7].

When it comes to Japan and South Korea, we can conclude that their security of supply is non-existent and they have to rely on an American presence in the Middle East.

Oil production in Europe has passed peak oil, with the United Kingdom passing peak in 1999 and Norway in 2001. The European decline rate as of 2006 was 7.6%. Europe will become increasingly dependent upon imports from the Middle East and North Africa (MENA).

The growing economy of China clearly demands more oil, and with today's correlation between growth in GDP and the use of oil we can expect an increase in the order of 10% per year in the coming years. Since 2000, production within China has increased by 0.4 Mbpd, compared with an increase in consumption of 2.7 Mbpd. Today, China has a self-sufficiency ratio of 50%. A 10% increase in consumption equates to 0.7 Mbpd, and with peak oil on the horizon they must obtain this oil by increasing their imports by the same amount. This is equal to a 20% increase in imported oil.

Figure 7.1. **Projected production of oil in China [7.3]**

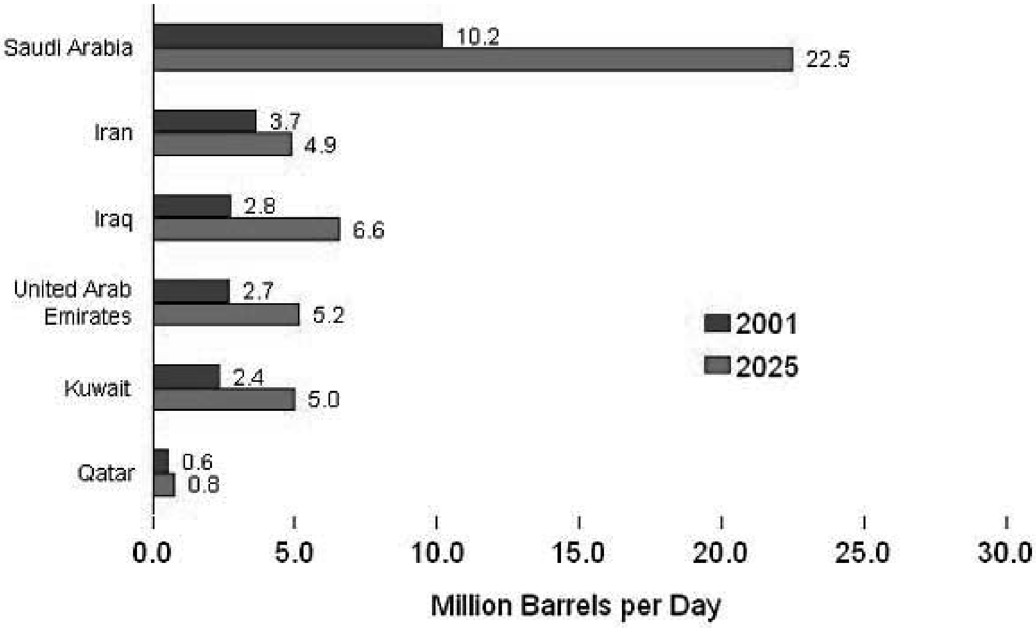


In mitigation strategies for the peak oil problem, China has indicated that it would like to maintain a self-sufficiency ratio of 50%. To increase quantities of self-produced oil they intend to: a) improve provable ratio; b) enhance oil recovery; and c) develop resources abroad.

Today, the China National Petroleum Corporation (CNPC) operates 65 projects in 25 countries around the world [7.3], where official policy will be to ring-fence production from these projects for consumption in China.

On 28 September 2004, the price of oil passed $50 per barrel, and on that day the author happened to be visiting the giant oilfield Bab in Abu Dhabi. Two days prior to this visit, at the conference on "The Gulf Oil and Gas Sector: Potential and Constraints", we had discussed calls on the Middle East made by Guy Caruso and the US EIA earlier that year [7.4]. In a reference scenario, an estimated increase in production was required such that a production of 28.2 Mb/d increased to 64.8 Mb/d – a 130% change (see Figure 7.2).

Figure 7.2: **Production capacity year 2001 and demanded production from US Energy Information Administration**
in units of million barrels per day



In the discussion, experienced oil experts stood up one by one and claimed that production should not be increased: they felt that it was time to think about future generations. The Middle East needed a maximum sustainable level of production; the words from Saudi Aramco were repeated.

When we discussed a potential increase in production from the Bab field, the Field Manager, Abdulla M. Al-Malood, pointed out that he would prefer to maintain a "sustainable production" level from the region and the fields currently under production. Any increase in production will stress the oilfield and increase the water cut, i.e. the percentage of water produced together with the oil. Furthermore, he also highlighted the fact that there were new regions that should be coming on stream as well as some smaller fields tied to the production of the current field. There is the possibility that several other oilfields can be put into production, but surely these fields should be reserved for future generations.

The fact that Saudi Arabia requires more end-products for domestic consumption means we can expect that new capacity will be built up in the country. In the future we can anticipate that exporting countries in the Middle East will change from the export of crude oil to increasing exports of oil products. As the region cannot grow enough food for the population, other types of employment are required to generate the necessary income.

We will also probably see Russia compensate for the decline in possible future crude oil exports by developing exports of oil products with higher revenue potential.

Venezuela is a small oil exporter, but an exporter with a strong political message; exports are needed for South America. Countries in Sub-Saharan Africa have a similar serious need for oil, but we do not expect to hear the same message from the exporting countries of West Africa that we hear from Venezuela.

A general conclusion is that, with peak oil on the horizon, exporting countries will reconsider the way they export oil in the future. Their actual reserves may be saved for future generations, and the pattern of export products may very well change.

7.1 References

[7.1] Marian Radetzki, Fyndigheter expanderar under resans gang; Brännpunkt, *Svenska Dagbladet*, 6 March, 2001

[7.2] Graham Paterson, Alan Greenspan claims Iraq war was really for oil, *The Sunday Times*, September 16, 2007, http://www.timesonline.co.uk/tol/news/world/article2461214.ece

[7.3 XiongqiPang, China Syndrome, http://www.aspo-ireland.org/index.cfm/page/aspo6

[7.4] Mahmoud M. Abdul Baqi and Nansen G. Saleri, Fifty-Year Crude Oil Supply Scenarios: Saudi Aramco’s Perspective, February 24, 2004, CSIS, Washington, DC, http://www.csis.org/media/csis/events/040224_baqiandsaleri.pdf

8. AWARENESS OF PEAK OIL

Dr. M. King Hubbert was the first person to become aware of the fact that oil production for a specific region could peak. In March 1956 he presented the famous paper, "Nuclear Energy and Fossil Fuels", for the American Petroleum Institute [8.1]. Hubbert used two different URR numbers for USA (now US-48) in his forecasts: 150 Gb and 200 Gb. Today, we know that the 200 Gb figure is closer to current statistical trends which provide a figure for URR of 220 Gb. The high-case scenario gave a peak in 1973. The most remarkable part of Hubbert's forecast is that, 44 years before the millennium, he predicted production to be at 4.1 Mbpd utilising the high case, and in fact actual production turned out to be 4.2 Mbpd.

The predicted scenarios for US-48 showed that the figure for URR is a crucial number in the calculation of future oil production. Because discoveries of oil peaked in the 1960s, and the industry hid this reality by not backdating this data, all estimates of future oil production before 1990 are clearly unreliable. Therefore, statements such as "the forecasts were wrong at the beginning of the 20th century and therefore they must be wrong at the beginning of the 21st century" have no scientific validity.

The first-ever Oil Depletion Conference took place in Uppsala in 2002 and in its wake the expression "peak oil" spread around the world. The debate about peak oil in Sweden commenced, and in 2004 the Royal Swedish Academy of Sciences (the organisation handing out the Nobel Prize in Physics and Chemistry) decided to appoint an energy committee, with its first mission being an examination of future oil production. In October 2005 a statement was drafted (see Appendix 1) and this statement, together with activities by ASPO in Sweden, led to the appointment of an Oil Commission by Swedish Prime Minister, Göran Persson [8.2].

Lines from the Commission report include:

"Declining access to conventional oil, in combination with our joint responsibility to stop global warming, will be a test of the world community's readiness to switch to energy systems that are more sustainable in the long term. Basically, it is a question of the will to show solidarity with present and future generations.

Sweden accepts this challenge.

In this document, we propose a number of far-reaching, concrete measures that can end our dependence on oil by the year 2020 and tangibly reduce our use of oil products. Our ambitious objectives are as follows:

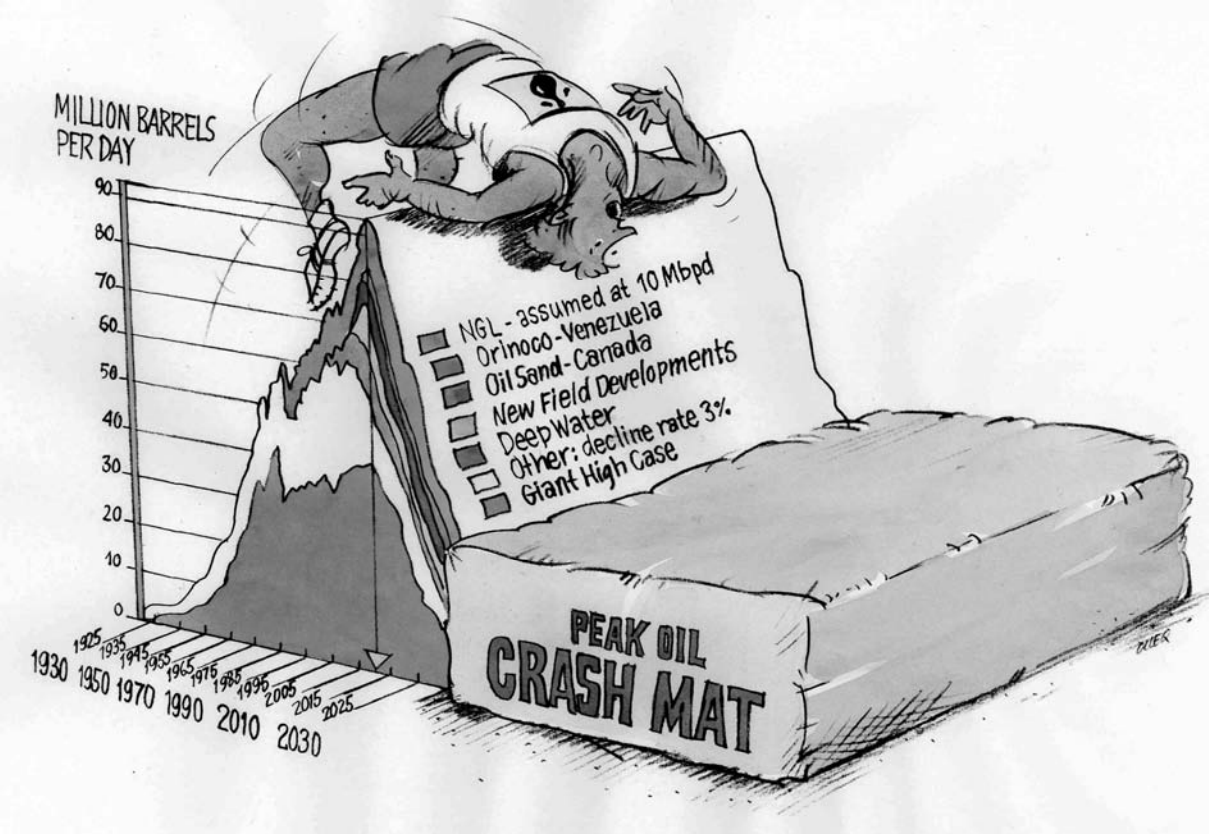
- *Through more efficient use of fuel and new fuels, consumption of oil in road transport shall be reduced by 40-50 per cent.*
- *In principle, no oil shall be used for heating residential and commercial buildings.*
- *Industry shall reduce its consumption of oil by 25-40 per cent."*

Industry and various agencies have frequently based decisions about future oil production on predictions by the Cambridge Energy Research Associates (CERA). In June 2006, CERA released a forecast that we criticized in an interview in the *Oil & Gas Journal* [8.3]. A reply to this critique came in the form of an article, published in the February 2007 issue of *Journal of Petroleum Technology* (JPT), by Peter M. Jackson from CERA. In the article, Jackson reviewed “Peak Oil Theory” and concluded that the “… ‘*peak oil lobby’ – a group of professionals that forecasts world conventional oil peaking within a decade – allows fear to replace careful analysis.*”

My reply [1.8] concluded: “*Figure 1 in the Jackson JPT article shows conventional oil production for 2006 at around 74 million barrels per day, and is forecast to increase to a maximum of 96 Mbpd in 2030, a plateau production until 2045 and a decline to 68 Mbpd in 2070. Integration under the CERA forecast plot gives a total conventional oil production of 2 050 million barrels. This is almost twice as much as we today have as conventional oil reserves, according to CERA. I hope that CERA now accepts to publish detailed analysis of the prediction, as we are doing*.”

It is very encouraging that US Secretary of Energy, Samuel W. Bodman, requested that the National Petroleum Council (NPC) should undertake a study on the availability of global oil and natural gas [1.12], and that he specifically mentioned peak oil (see section 1.3). The reply to Mr Bodman’s request was a huge disappointment. It is unbelievable that the Council “involving more than 1 000 people actively involved in energy” could not give an answer to Mr Bodman’s question about peak oil. The 422-page report is simply a description of how to circumnavigate the reality of peak oil.

Figure 8.1: **Passing peak oil we must land on a “crash mat”**



At the ASPO-6 Conference in Cork, Ireland, on 16-17 September 2007, Dr. James Schlesinger, the United States' First Secretary of Energy, was invited as a keynote speaker. For him, peak oil is no longer a question, simply a stark reality. His statement, "*And therefore to the peakists I say, you can declare victory. You are no longer the beleaguered small minority of voices crying in the wilderness. You are now mainstream. You must learn to take yes for an answer and be gracious in victory*", was a great moment. But I am also willing to accept his request that we should be "gracious in victory". Peak oil must be addressed at all levels in today's society and we need to work together.

We have climbed high on the "Oil Ladder" and yet we must descend one way or another. It may be too late for a gentle descent, but there may still be time to build a thick crash mat to cushion the fall.

8.1 References

[8.1] M. King Hubbert, , Publication No. 95, Shell Development Company, Exploration and Production Research Division, Houston, Texas, June 1956; http://www.oilcrisis.org/hubbert/1956/1956.pdf

[8.2] The Swedish Oil Commission, report from June 21, 2006, "Making Sweden an OIL-FREE Society" (http://www.sweden.gov.se/sb/d/574/a/67096)

[8.3] Paula Dittrick, CERA study disputes peak-oil capacity growth arguments, *Oil & Gas Journal*, Vol. 104, Issue 31, Aug 21, 2006.

9. ACKNOWLEDGMENTS

This paper was written at the request of the OECD and the International Transport Forum, for presentation at a Round Table on "**Oil Dependence: Is Transport Running Out of Affordable Fuel?"**, held in Paris on 15-16 November 2007. I would like to express my thanks to the organisers for allowing peak oil to be a part of the discussion.

It would not have been possible to present some of the data in this report without the outstanding work of my students, Mikael Höök, Kristofer Jakobsson, Aram Mäkivierikko, Fredrik Robelius and Bengt Söderbergh. Thank you for all of your work.

Finally, I would like to thank Simon Snowden (University of Liverpool Management School, UK) for proofreading the paper and the provision of feedback.

ANNEX: STATEMENTS 14 OCT 2005

Statements on Oil
by the Energy Committee of the Royal Swedish Academy of Sciences

Introduction

The Royal Swedish Academy of Sciences is an independent, non-governmental organisation, with expertise in most of the sciences as well as economical, social and humanistic fields. The Academy has recently established a committee to consider today's important energy issues that need our full, unbiased attention. The Energy Committee has a national as well as a global perspective and will summarize scientific knowledge on the supply and use of energy as well as the predicted impacts on society over the coming fifty years. Sustainability and environmental considerations are essential for any future energy system. Readily available, inexpensive and environment-friendly energy provides the foundation for economic growth and prosperity.

The Energy Committee has selected a number of subjects to be studied in some depth. One of these deals with oil and related carbon-based fuels. Therefore, the Committee organised, together with the Committee of Energy and Environment of the Royal Academy of Engineering Sciences, a Seminar with the title, "Running out of Oil – Scientific Perspectives on Fossil Fuels", held at the Academy on 26 May 2005. Prior to the Seminar, the Energy Committee conducted a hearing with the seminar participants. More information about this seminar can be found on the Academy's web page at www.kva.se. The Committee also arranged a hearing with speakers in an Uppsala Seminar on "Global oil reserves" on 23 May 2005, together with the Graduate School of Instrumentation and Measurements (AIM). Members of the Committee participated in the Uppsala Seminar. Some essential points brought up at the hearings and seminars are highlighted below. It should be pointed out that the perspective given here is not purely scientific, since there are important social, political and technical factors that need consideration.

General Remarks

It is very likely that the world is now entering a challenging period for energy supply, due to the limited resources and production problems now facing conventional (easily accessible) oil. Nearly 40% of the world's energy is provided by oil, and over 50% of the latter is used in the transport sector. An increasing demand for oil from emerging economies, such as China and India, is likely to further accentuate the need for new solutions. In addition, it is important that the poorer countries have access to oil at reasonable prices to meet their development goals. This places an additional burden on responsible, mature economies. Compared to many developing countries, the same percentage increase in the crude oil price will be less problematic for Sweden and other European countries because of our tax system (crude oil's share in the gasoline price is quite small – *ca.* 25% – compared to taxes). The poor countries will suffer most from an increased price.

China, India and several nations in South-East Asia and Latin America are now experiencing rapid economic development. Continued high oil prices will jeopardize their chances of economic growth. Many countries, for example in Africa, may not even be able to develop economically in the absence of cheap oil. With China and India emerging as engines of the global economy, the sharp increase in oil prices which we are witnessing today could lead to a serious international economic recession, similar to those that followed the oil price increases in 1973-74 and 1981. The European economies may be severely affected.

There is at present an extreme dependence on supply from the Middle East, which holds more than 60% of global oil reserves. A key country is Saudi Arabia, which is supposed to hold about 20% of the global reserves of conventional oil and much of the world's spare capacity. Some analysts maintain that there are inherent technical problems in the Saudi oilfields, but this is not an uncontested viewpoint. It is uncertain by how much oil production in the Middle East can be increased in the next few years and to what extent it would be in the interest of these countries to greatly increase production. It is clear that, even in these countries, conventional oil is a limited resource on which they are almost totally dependent. It is, however, also clear that the countries of the Middle East are undergoing massive internal and regional changes, which may have negative consequences for the global oil supply system. Mitigation measures must be initiated in the next few years in order to secure a continued, adequate supply of liquid fuels, especially for the transport sector. Over the longer term, completely new solutions are required. Therefore, increased R&D (Research and Development) in the energy sector is urgently needed.

Key Points

1. Shortage of oil

The global demand for oil is presently growing by nearly 2% per year and the current consumption is 84 million barrels per day (1 barrel=159 litres) or 30 billion barrels per year. Finding additional supplies to increase the production rate is becoming problematical, since most major oilfields are well matured. Already 54 of the 65 most important oil-producing countries have declining production, and the rate of discoveries of new reserves is less than a third of the present rate of consumption.

2. Reserves of conventional oil

In the last 10-15 years, two-thirds of the increases in reserves of conventional oil have been based on increased estimates of recovery from existing fields and only one-third on discovery of new fields. In this way, a balance has been achieved between growth in reserves and production. This cannot continue. Fifty per cent of the present oil production comes from giant fields and very few such fields have been found in recent years. Oil geologists have a wide range of opinions on how much conventional oil there is yet to be discovered, but new reservoirs are expected to be mainly found in the deeper water, outer margins of the continental shelves, and in the physically hostile and sensitive environments of the Arctic, where the production costs will be much higher and lead times much longer than they are today. A conservative estimate of discovered oil reserves and undiscovered recoverable oil resources is about 1 200 billion barrels, according to the US Geological Survey; this includes 300 billion barrels in the world's as yet unexplored sedimentary basins.

3. *The Middle East's key role*

Only in the Middle East and possibly the countries of the former Soviet Union is there a potential to significantly increase production rates to compensate for decreasing rates in other countries. Saudi Arabia is a key country in this context, providing 9.5 million barrels per day (11% of the current global production rate). Their proven reserves are 130 billion barrels and their reserve base is said to include an additional 130 billion barrels. Iraq also has considerable untapped oil reserves.

4. *Unconventional oil resources*

In addition to conventional oil, there are very large hydrocarbon resources, so-called unconventional oil, including gas (*ca.* 1 000 billion barrels of oil equivalent, much of which could be converted to liquid fuels), heavy oil and tar sands (*ca.* 800 billion barrels) and oil shales (*ca.* 2 700 billion barrels). Coal, from which liquid fuels can be produced, and methane hydrates provide a vast additional potential. During a transition period, gas often available adjacent to the oil fields will help to bridge future deficits of conventional oil. With the exception of gas, all unconventional oil is expensive to produce (*ca.* $20-40/barrel) and exploitation involves significant environmental problems. At $40 oil, which is now commonly accepted as the long-term equilibrium price, the cost of developing unconventional oil is less problematic. (see Point 7 below). At present, 1 million barrels of oil per day come from Canadian tar sand and 0.6 million barrels from Venezuelan heavy oil. The Canadian Government estimates that by 2025 the daily production rate will have increased to 3 million barrels per day. Thus, the problem with these unconventional oils is not so much price as lead times and non-price-related aspects, such as the effects on the environment and availability of water and natural gas for the production process.

5. *Immediate action on supplies*

Forceful measures to improve the search for and recovery of conventional oil, as well as improving the production rate of unconventional oil, are required to avoid price spikes, which would lead to the instability of the world economy in the next few decades. Improved recovery of oil in existing fields can be expected. The estimated reserves of conventional oil are, however, located primarily in unexplored sedimentary basins, in environments difficult to access, and a substantial part has yet to be found! Sizeable contributions from unconventional oil need time (some decades) to become really effective. It is necessary to have public funding for long-term, petroleum-related research, since this must not be an exclusive task for the oil companies.

6. *Liquid fuels and a new transport system*

Oil supply is a severe liquid fuels problem and less of a general energy supply problem; 57% of the world's oil is consumed in the transport sector. Unless governments ration oil, there will never be a shortage of oil; just increasing prices. Major programmes therefore need to be implemented to develop alternatives to oil in the transport sector. Until these measures have been introduced (which may take one to two decades), demand for oil for the needs of a globally expanding transport sector will continue to rise; other users of oil will suffer, including those concerned with power generation.

7. *Economic considerations*

At present, the high oil prices are due to the limitations of worldwide production, refining and transportation capacities. Furthermore, the price is influenced by the threat of terrorist attacks on the world's oil supply, transport systems and infrastructure. In the long run, the price of crude oil will be determined by the price of substitutes. Some estimates indicate that oil may be produced from tar sand at a price of USD 20-25 a barrel, compared to the present cost of about USD 5 for Saudi Arabian oil. Liquid fuels from coal could be produced for many decades; cost estimates vary greatly and generally exceed USD 30. Factors that are hard to estimate are environmental requirements, taxation levels and profit margins. However, we can anticipate continued high oil prices, as long as the pressure from the expanding Asian economies is maintained.

8. *Environmental concerns*

Unconventional oil will significantly extend the length of the hydrocarbon era, assuming that the negative impacts on the environment can be avoided. Constraints similar to those imposed on other fossil fuels (for example, emission controls and CO_2 sequestration) will be necessary and provide major challenges for industry. The impact on the environment in general, and on the atmosphere and climate in particular, produced by combustion of fossil fuels, is not considered here. However, it is worth noting that such considerations provide further support for the conclusions presented below.

9. *Increased R&D and international efforts*

To avoid acute economic, social and environmental problems worldwide, we need a global approach, with the widest possible international co-operation. Activities in this direction have started and they should be strongly encouraged and intensified; the technically advanced countries having a particular responsibility. Considerably increased resources for R&D on alternative non-fossil energy sources, as well as on the efficient and sustainable use of energy, particularly electricity, are necessary. In order to develop a sustainable energy system beyond the fossil fuel era, we need a full system analysis of the energy sector based on realistic time scales. The Energy Committee intends, in the next couple of years, to study other sources of energy and evaluate their relative merits and impacts on the environment and climate.

Members of the Energy Committee at the Royal Swedish Academy of Science:

Sven Kullander, Professor em., Uppsala University
Gia Destouni, Professor, Stockholm University
Harry Frank, Professor, Mälardalens University
Karl Fredga, Professor em., Uppsala University
Bertil Fredholm, Professor, Karolinska Institutet
David Gee, Professor em., Uppsala University
Karl Grandin, Ph.D., Centre for History of Science
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Bengt Kasemo, Professor, Chalmers Institute of Technology
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APPENDIX

RESERVE-DRIVEN FORECASTS FOR OIL, GAS AND COAL AND LIMITS OF CARBON DIOXIDE EMISSIONS

Peak Oil, Peak Gas, Peak Coal and Peak CO_2

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TABLE OF CONTENTS

Uppsala, October 2007

ABSTRACT

The increase of carbon dioxide (CO_2) in the atmosphere is caused by an increasing use of fossil fuels; natural gas, oil and coal. This is believed to have contributed to an increase in the global surface temperature of the order of one degree.

In 2000, the Intergovernmental Panel on Climate Change (IPCC), released 40 emission scenarios, said to be “images of the future, or alternative futures”, and according to IPCC, “they are neither predictions nor forecasts.” These scenarios were based on fossil fuel resources rather than recoverable reserves (see preceding chapters).

This analysis is based on realistic reserve assessments. Resources that cannot be transformed into reserves are not considered. First, we conclude that CO_2 emissions from burning reserves-based oil and gas are lower than predicted by all of the IPCC scenarios, and emissions from coal are much lower than portrayed in the majority of the scenarios.

IPCC emission scenarios for the period 2020 to 2100 must be altered to more accurately reflect the fossil fuels that are practically available.

Climate change is current, with more changes to come, and poses an enormous problem for our planet. However, the world’s greatest problem is that too many people must share too little energy.

1. INTRODUCTION

The issues of climate change and future increases in temperature have become part of our everyday life, and central to this debate is the role of carbon dioxide. The fossil fuels we use contain both carbon and hydrocarbon compounds, and when we burn these products carbon dioxide is released together with a certain amount of energy.

However, in the climate debate that now rages, it appears that existing quantities of fossil fuels are not perceived as a problem. The issue is always assumed to be the excessive use of hydrocarbons and coal. The idea that the combined volumes of these fuels are insufficient to yield the levels of carbon dioxide (CO_2) necessary to cause the changes in climate predicted is not expressed anywhere.

At Mexico's enormous Cantarell oilfield, production is declining very rapidly. In 2005 the Mexican oil company Pemex presented two scenarios for how much oil Cantarell would ultimately produce; an optimistic estimate with an extraction rate of 50% of the original oil in place, and a more pessimistic estimate of only 30%. For Pemex and the Mexican Government it is, of course, a severe blow that reality now appears consistent with the pessimistic scenario; but this may mean our climate stands to benefit. We have now come to an important decision point. Shall we regard the oil that remains underground as a resource that can cause future carbon dioxide emissions or shall we accept that this finite resource is in fact inaccessible? Scenarios used by the Intergovernmental Panel on Climate Change (IPCC), are based upon the consideration that all oil in place is a source for future CO_2 emissions. Our analysis uses only those reserves judged to be technically and economically available now and in the future, and this makes the predictions "reserve driven".

The production of oil, gas and coal are limited by today's reserves, the fraction of the resources that can be produced economically, and reserves that can be found in the future. You must find oil before you can produce it.

Oil reserves currently displaying declining production have a very limited potential to grow, and the fact that the majority of the productive oilfields are now in decline provides us with the possibility of estimating the maximum emission of CO_2 from oil.

Natural gas fields, on the other hand, have a high recovery factor because gas moves easily through rock strata. Enhanced recovery is not part of the future of these fields and discovery trends are the primary driving parameters.

Coal can only be extracted using different kinds of mining. Areas for surface mining are shrinking due to environmental and social considerations. The next generations' underground mines will be very expensive. In Germany, modern mining is more than twice as expensive as the market price of coal. Reported new reserves are in general smaller than reported earlier, contrasted with growth in existing oil fields.

If we take the reserves reported in the *BP Statistical Review* [1] as a potential for future emissions, we find that gas will produce 400 billions metric tonnes of CO_2, oil 600 billion metric tonnes of CO_2, and coal 2 000 billion metric tonnes of CO_2. It has been said before, and we would once again like to point out the fact, that coal is the main problem when considering future emissions.

2. EMISSIONS SCENARIOS BY IPPC

The IPCC Special Report on Emissions Scenarios [2] describes 40 scenarios for the future and predicts the extent of greenhouse gas emissions associated with such developments. These scenarios are based on reviews of the literature, the development of narrative *storylines* and the quantification of these storylines with the help of six different integrated models from different countries. The report illustrates that future emissions, even in the absence of explicit climate policies, depend very much on the choices people make: how economies are structured, which energy sources are preferred and how people use available land resources. Restriction of reserves is not part of the game.

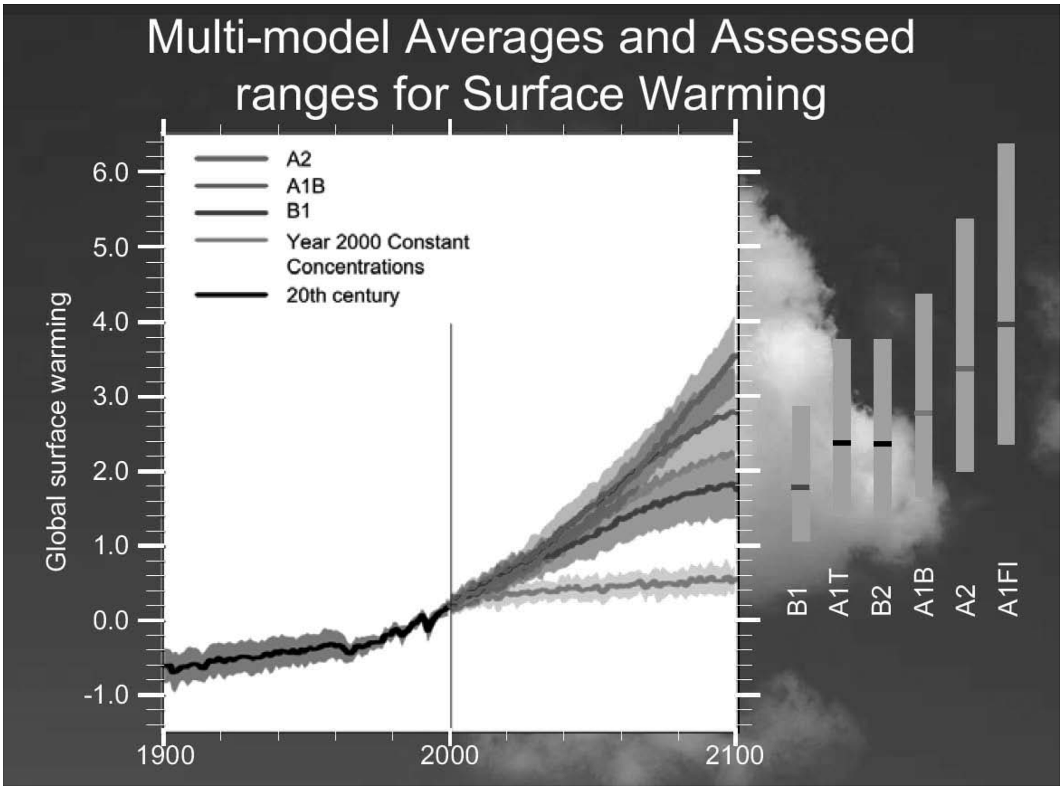
The scenarios can be seen as images of the future, or alternative futures, but they are not predictions and they are not forecasts. Different assumptions about the future help create different images of how the future might unfold. The best way to describe the enormous computer models is to look at them as some kind of giant “IPCC-SimCity games”[10].

The families in the “game” are called A1, A2, B1 and B2. Every family has a predetermined future in terms of the growth of population and GDP, land use, available resources and technology development. Each family creates its footprint in terms of emissions of CO_2 from the use of oil, gas and coal. The emissions are then used in climate models and finally a change of global surface temperature is calculated.

3. IPCC CLIMATE MODELLING

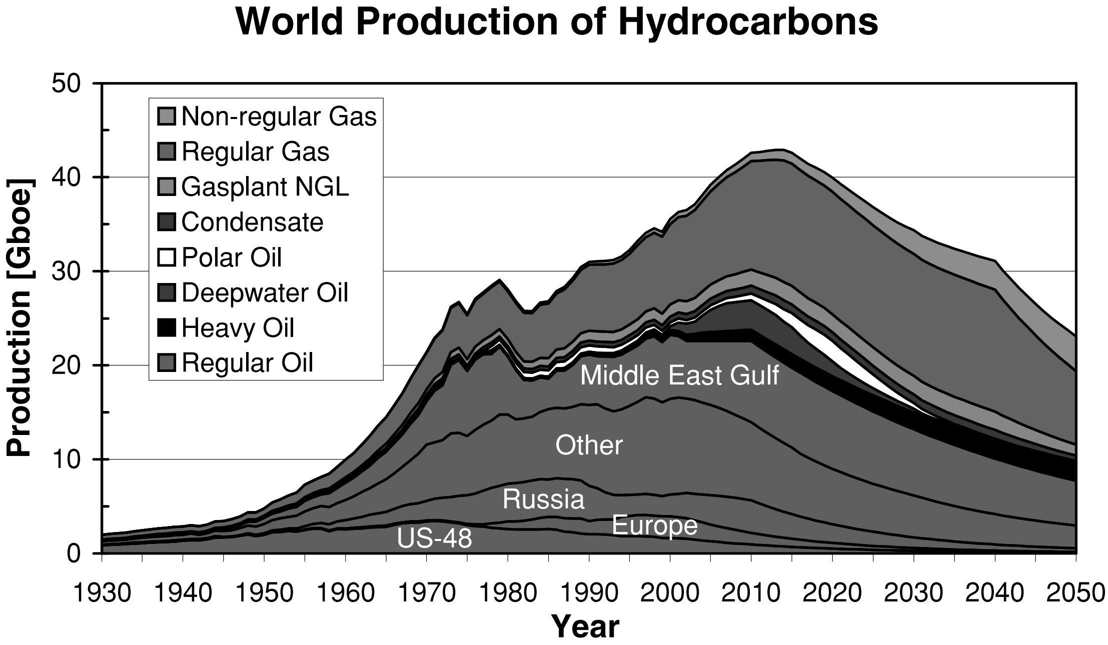
In the modelling of climate change, the different emission scenarios are the central component, with different curves displaying changes in temperature and labelled according to the different family names. The most utilised family scenario, showing an unacceptable threat to our planet, is the A2 family. If this scenario is allowed to develop, the temperature by 2100 will be a whole 3.6 degrees higher than today. The most optimistic scenario is B1, and this least troublesome family causes a temperature increase of only 1.8 degrees (Figure 1), compared with the reference year 1990[2]. The EU has proposed a target of below 2 degrees.

Figure 1. **Modulated averages and assessed ranges for surface warming, according to IPCC**



The prerequisite for each of these scenarios and the subsequent temperature increase they represent is that we consume large volumes of oil, gas and coal. The fact that the IPCC calls upon our politicians to make decisions that will discourage use of fossil fuels creates an impression that the requisite fossil fuel reserves exist on a large enough scale.

Figure 2. **The world's production of all hydrocarbons, excluding tar sand, bitumen, oil shale and methane hydrate, according to the 2002 scenario** [2]



Regular oil production is divided into production from different regions. US-48 represents the USA excluding Alaska and Hawaii, and the group "Other" represents the rest of the world.

4. FUTURE OIL, GAS AND COAL PRODUCTION AND IPCC EMISSION SCENARIOS

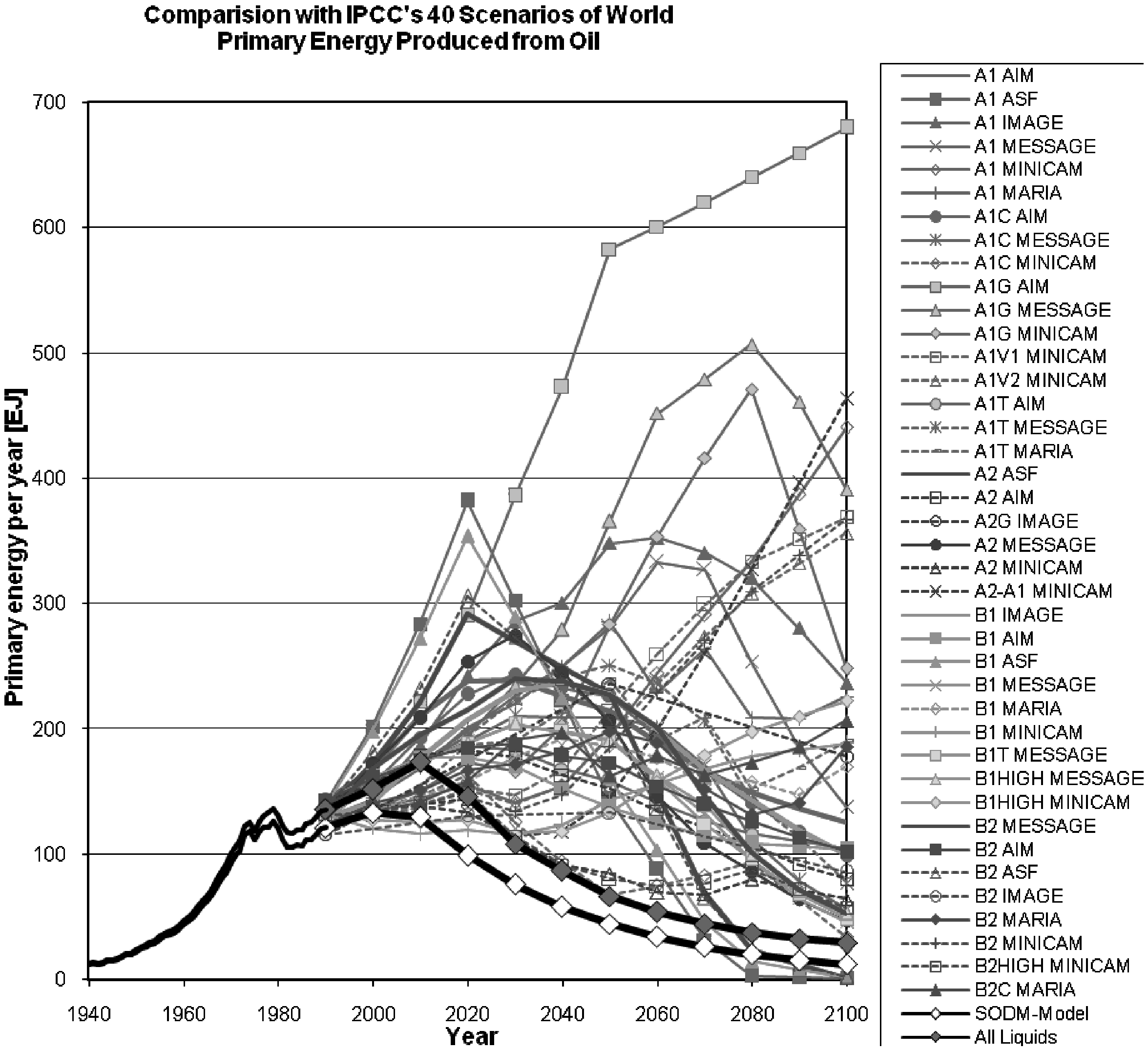
In 2003, the Uppsala Hydrocarbon Depletion Study Group (UHDSG) performed a detailed study on "World Oil Reserves with a Comparison to IPCC Emissions Scenarios" [3]. The different IPCC emissions scenarios are detailed in this work. Oil and gas production were determined according to the depletion model (DM) described in the paper "The Peak and Decline of World Oil and Gas Production" [4], and the sum of the oil and gas production is illustrated in Figure 2.

The IPCC describes the fraction of different fossil fuels used in the scenarios in terms of primary energy per year, and the production figures shown in Figure 2 can be transformed into energy distributions. Figures 3 and 4 show these distributions in comparison with the IPCC emission scenarios.

Just take a glance at Figures 3 and 4 and you will realise that the planet cannot provide the amount of energy from hydrocarbons (oil and natural gas) that the IPCC needs to drive the scenarios presented in 2000.

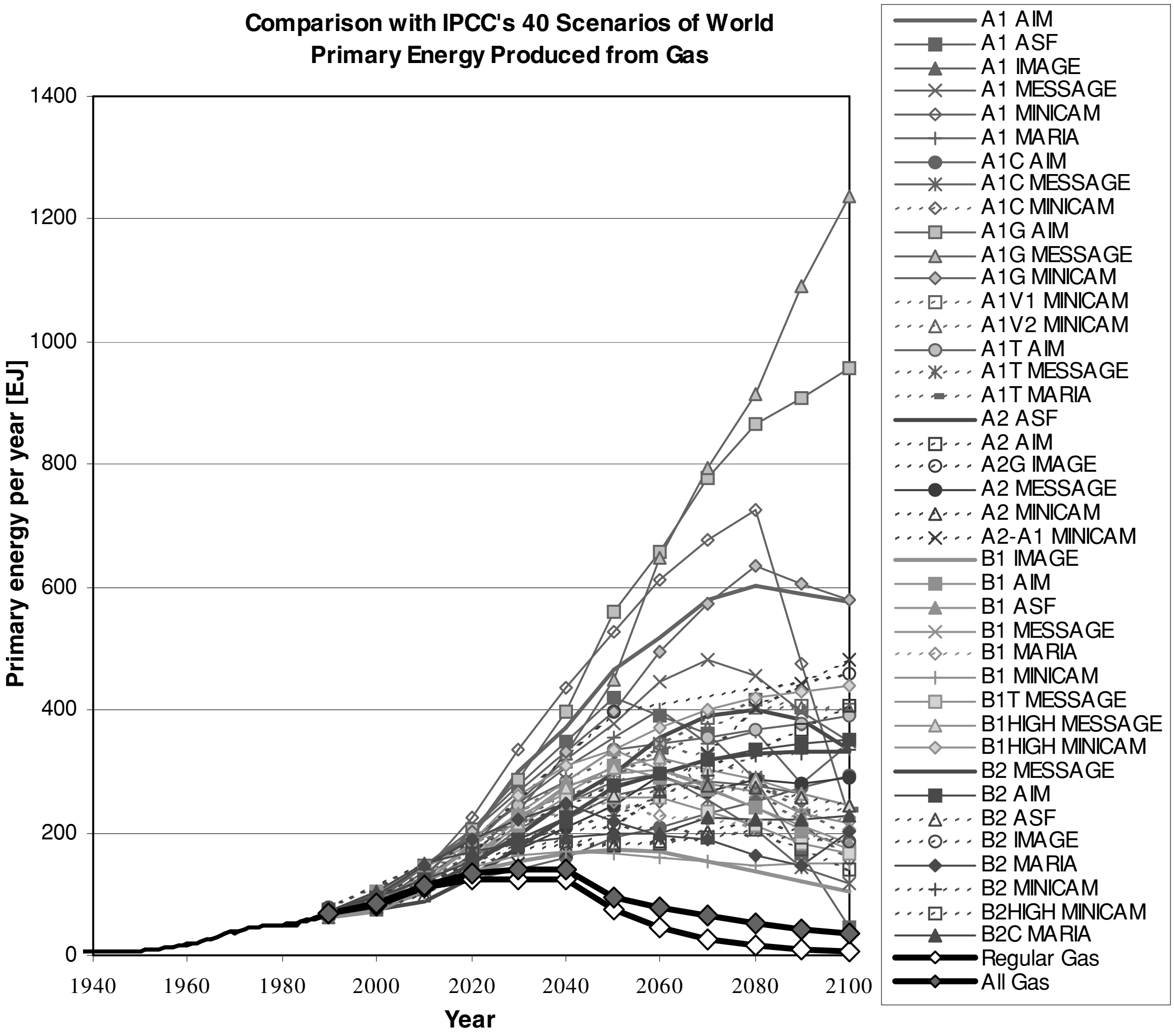
This can be shown in an even more convincing way by adding each year's consumption as presented in Figure 5. The time structure of the distributions given in Figures 3 and 4 can differ, as well as the total energy consumption given in Figure 5, and if the numbers are too low by a factor of 50% we may just about attain the best-case scenario presented by IPCC.

Figure 3. **IPCC's 40 scenarios on world primary energy produced from oil 1990-2100 compared to the oil production according to the oil depletion model 1930-2100**



Note: The group "all liquids" includes heavy oil, extra heavy oil, deepwater oil, polar oil, gas plant NGL and condensate.

Figure 4. **IPCC's 40 scenarios on world primary energy produced from gas, 1990-2100, compared to the gas production according to the oil depletion model 1930-2100**



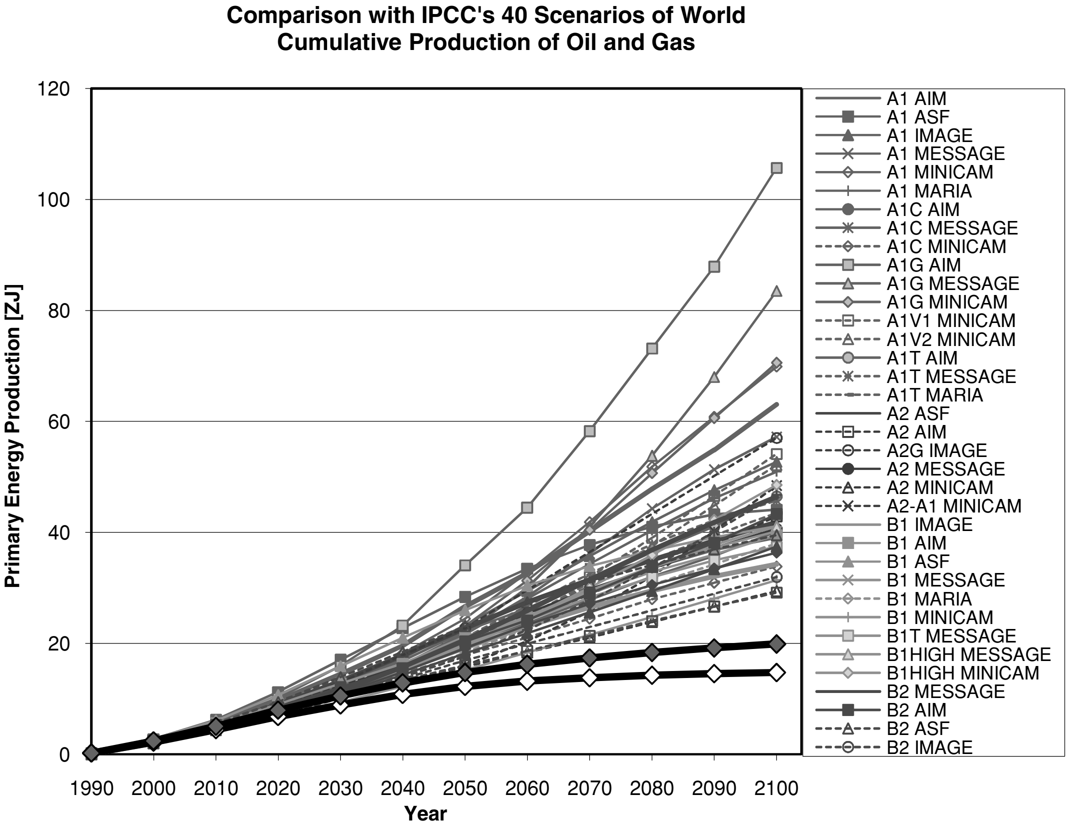
Note: The group "all gas" includes non-regular gas, e.g. coal bed methane.

When this data was presented in 2003, the *New Scientist* wrote an article concerning our findings [5] (see Appendix 1):

> *"Nebojsa Nakicenovic, an energy economist at the University of Vienna, Austria, who headed the 80-strong IPCC team that produced the forecasts, says the panel's work still stands. He says they factored in a much broader and internationally accepted range of oil and gas estimates than the "conservative" Swedes.*
>
> *Even if oil and gas run out, "there's a huge amount of coal underground that could be exploited", he says. Aleklett agrees that burning coal could make the IPCC scenarios come true, but points out that such a switch would be disastrous."*

The same day as this article was released, CNN interviewed the author live and wrote about the article on their website [6].

Figure 5. **IPCC's 40 scenarios on world cumulative primary energy produced from oil and gas compared to cumulative oil and gas production according to the oil depletion model**



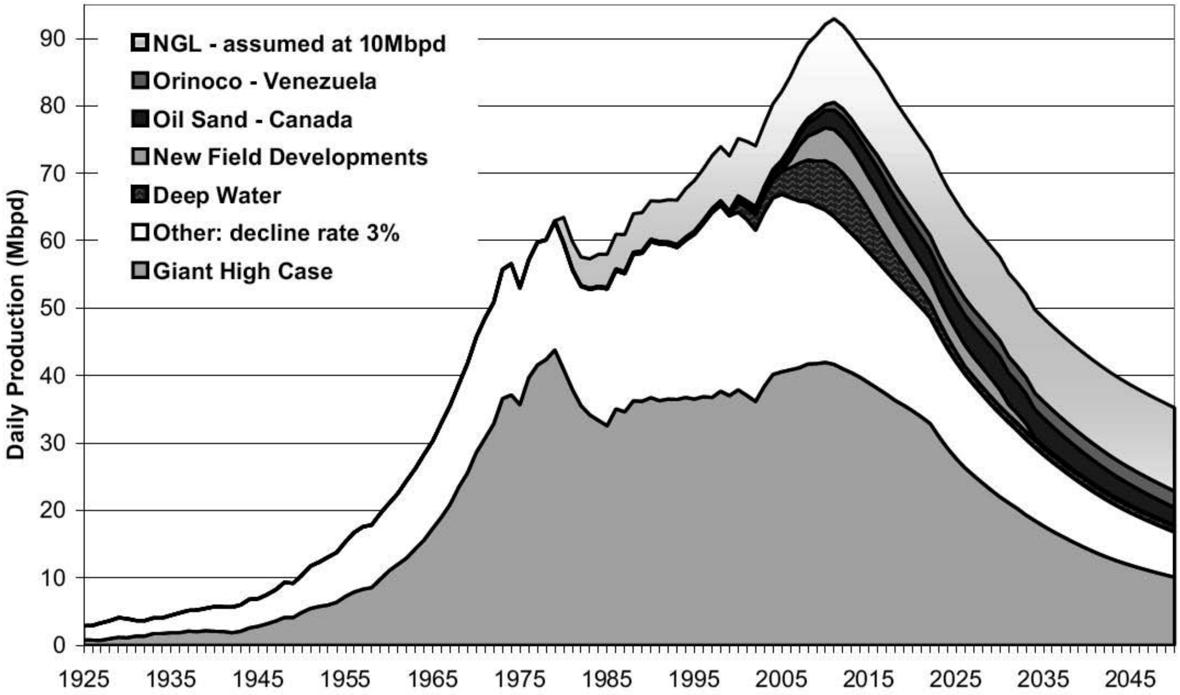
Note: The group "All Oil and Gas" includes heavy oil, extra heavy oil, deepwater oil, polar oil, gas plant NGL, condensate and non-regular gas, e.g. coal bed methane.

Most puzzling is that Nebojsa Nakicenovic can reaffirm the panel's work in light of the results shown in Figures 3, 4 and 5. At that time, everybody felt that it didn't matter if you were right or wrong about oil and gas because there was so much coal, and coal emits much more CO_2 than oil and gas. This is correct, and comparatively for 2005 all of the emissions produced by burning gas in the world only equate to the emissions from burning coal in China. On this basis, UHDSG decided to do an even more detailed study which included figures from coal.

We have now completed this study, based upon a detailed analysis of future oil and coal production, the two major CO_2 emitters [9]. By breaking down oil production into seven well-defined parts, we can now give a time-frame for the moment when we will reach the maximum production rate for oil, "Peak Oil", the historical peak in production. It will occur between 2008 and 2018. If the world's giant oilfields (those fields that produce 60% of the world's oil) behave in a similar manner to Mexico's Cantarell field, we have the basis for a "worst-case scenario" with a production peak in 2008. If instead they follow the best prognosis for Cantarell, and we simultaneously reduce our consumption, then we get a "best-case scenario" with maximum production in 2018. When discussing CO_2 emissions we should use a "high-case scenario" (Figure 6), a picture comparable to the depletion model [2].

Figure 6. **The sum of the production from the seven different parts as defined in the figure with the "Giant High Case" scenario**

This is a rather optimistic scenario

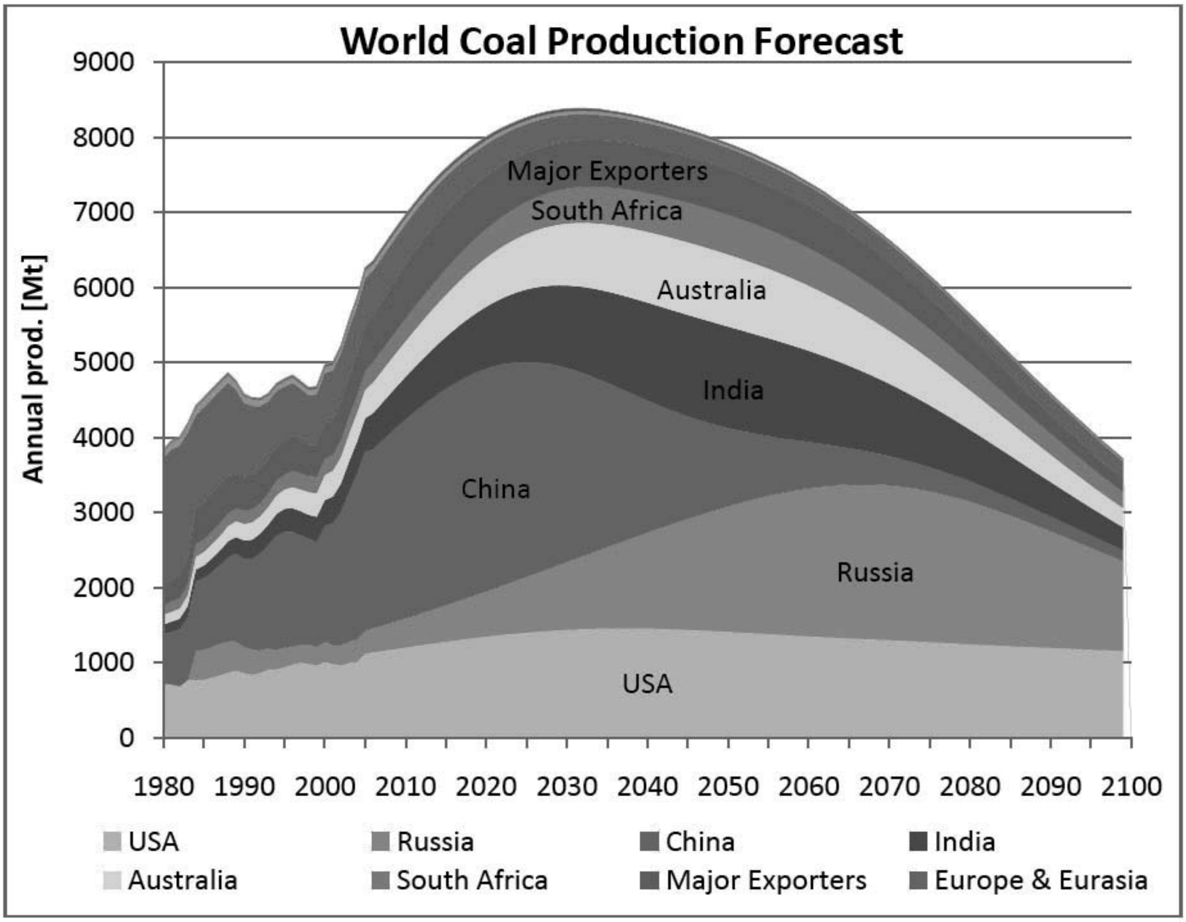


We can now, according to our forecast, calculate how much energy/carbon dioxide we can expect to produce this century if oil is used accordingly, and compare it with the energy requirements of the IPCC families. To our amazement, we see that families A1, A2, B1 and B2 require more oil than is realistic.

If we extend our analysis and study future natural gas production with what the IPCC families require, we get an even clearer picture. Natural gas production is declining in North America as is production in the gigantic Russian gas fields in northwest Siberia, which today account for 90% of Russian production. Projects planned for the production of diesel fuel from natural gas in Qatar are being cancelled, and the intended construction of liquefied natural gas reception terminals in the USA and Europe are being downsized, because global production of liquefied natural gas is now not expected to reach levels planned for a few years ago. Natural gas is considered by many to be a "transition fuel" to a future, renewable-based society. Today the transition seems to be shorter than previously believed, but in terms of carbon emissions once again we may stand to benefit.

The third component to be considered when discussing carbon dioxide emissions is coal. The common belief is that virtually unlimited quantities of coal exist, but when we make detailed analyses of production profiles in those six nations that have 85% of the world's coal reserves (see Figure 8), the USA, China, Russia, Australia, India and South Africa, we soon discover clear signs that coal production in particular regions has reached maximum capacity [7]. Furthermore, we see a decline in production of the best coal, i.e. that which has the highest energy content. In the USA, the world's second largest coal user, the volume of coal consumed is increasing but the actual energy content of the coal used is decreasing. The USA has reached a coal maximum, "Peak Coal", in terms of energy content.

Figure 7: **Possible world coal production** [7]



China will soon reach its maximum coal production capacity too and we will then be in a situation where Russia alone sits on the last great coal reserves. That moment in history when we reach "Peak Coal" is determined by Russia's future coal production. This forecast is based on open data, and what we see in our analysis is that every country that makes a new reserve estimate is down-scaling their reserves. Finally these production profiles are compared with the IPCC emission scenarios for coal (as for oil and gas, most of the scenarios would not be fulfilled).

The total sum of all fossil fuel resources that industry considers accessible is reported every year in the *BP Statistical Review*. If we use this optimistic value then the total energy available from all reserves of oil, natural gas and coal equals 36 ZJ (zettajoules, 1×10^{21} joules), a massive quantity. This is more than our research group considers possible but is still less than that reported for all of the scenario families, A1, A2, B1 and B2. The available energy from fossil fuels is insufficient.

Family A2 is our "worst case" in terms of temperature increase, so let us take a look at its thirst for energy. In the years to 2100 the IPCC estimates that A2 requires between 70 and 90 ZJ, in other words, double the amount that industry believes is accessible. There is then another small detail that is never discussed, namely that all of the IPCC families require fossil fuel energy subsequent to the year 2100 (see Figures 3, 4 and 8).

Figure 8: **IPCC's 40 scenarios on world primary energy produced from coal, 1990-2100 compared to coal production according to our data**

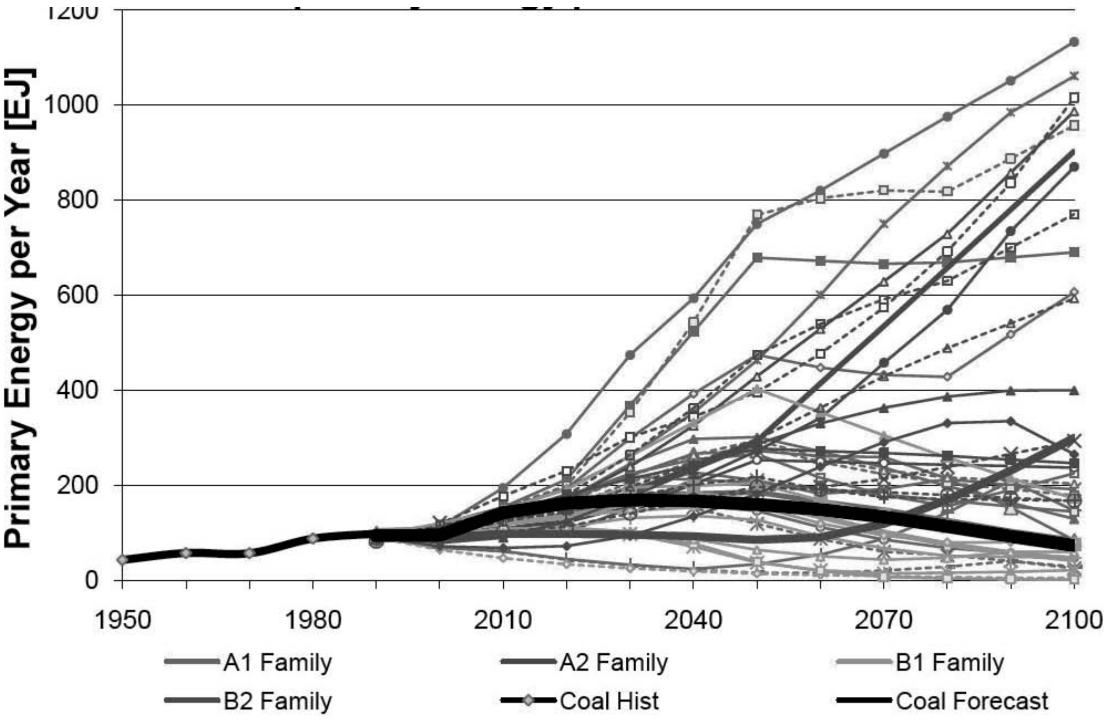


Figure 9: **Cumulative fossil fuel usage for family A2**,
70 to 90 Zeta Joule, compared with the total fossil reserves,
according to BP *Statistical Review*, 36 Zeta Joule.

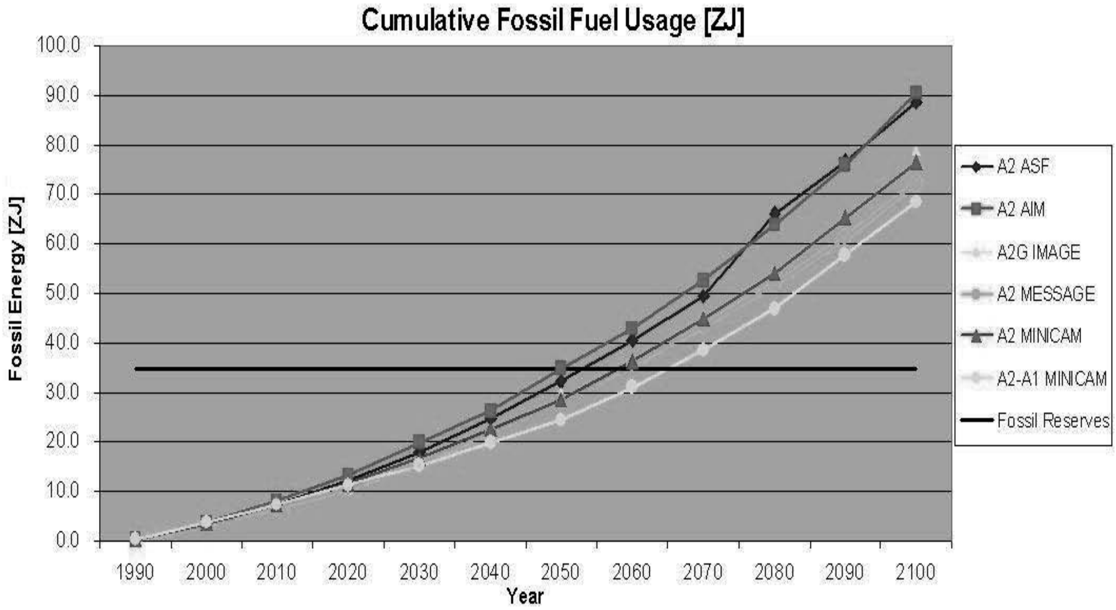
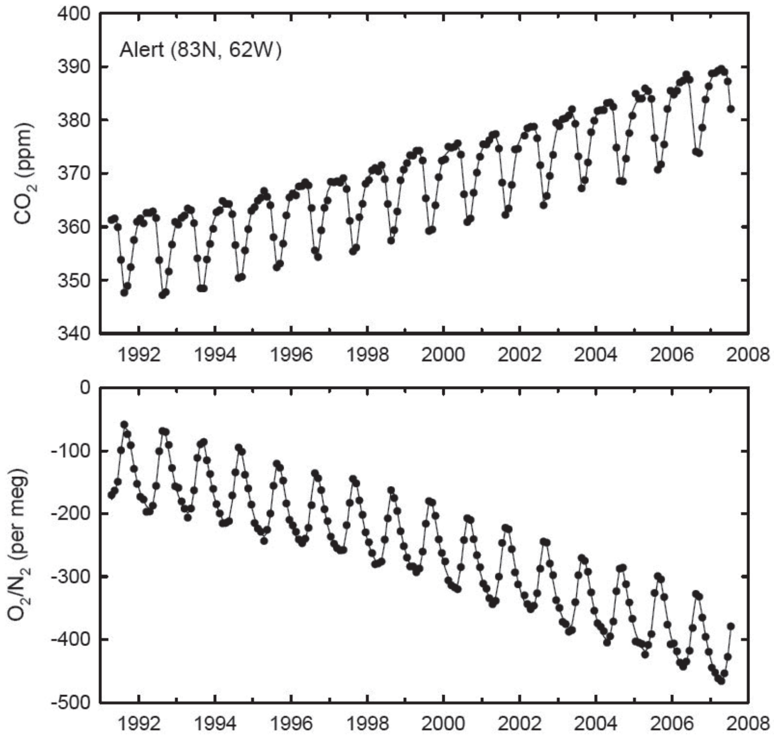


Figure 10. **Correlations between concentration of carbon dioxide (CO_2) in parts per million (ppm) and the ratio between oxygen and nitrogen per meg in the atmosphere** [8]



5. CONCLUSIONS

It is not necessary here to enter into the debate about fossil fuels as the cause of increased CO_2 concentration in the atmosphere. When burning fossil fuels oxygen (O_2) in the atmosphere is consumed and CO_2 produced, giving rise to a decline in O_2 concentration, a fact illustrated in Figure 10 [8]. Furthermore, it is known that CO_2 is a greenhouse gas and that a higher concentration will yield an increase in the surface temperature of the planet. The increase of CO_2 during the last 100 years may already be more than the climate can take. During the period 2008-2020 we will see a plateau (or a small decline) in the production of oil, but an increase in gas and coal consumption will lead to a combined higher emission of CO_2 by 2020 than seen today. *The conclusions of this paper do not mean that we should not worry about emissions. The big question is what will happen after 2020 and for the duration of the 21st century?*

The IPCC states that their scenarios can be seen as images of the future (or alternative futures) and that they are neither predictions nor forecasts but different assumptions about the future that can help us understand how the future might unfold. *The author's conclusion is that the IPCC emission scenarios are absolutely unrealistic about the time frame 2020 to 2100 and these "alternative* *futures" should no longer be given credence.* We need a realistic emissions scenario. The Uppsala Hydrocarbon Depletion Study Group has now combined all of its research for oil, gas and coal and proposes a much more realistic starting point than the time frame 2020 to 2100 [9].

Climate change is current with more changes to come; furthermore, climate change is an enormous problem facing our planet. However, *the world's greatest problem is that too many people must share too little energy. In the current political debate we presumably need to replace the word "environment" with "energy", but thankfully the policies required to tackle the energy problem will greatly benefit the environment.*

6. REFERENCES

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[10] Simcity Society, http://Simcity.ea.com/

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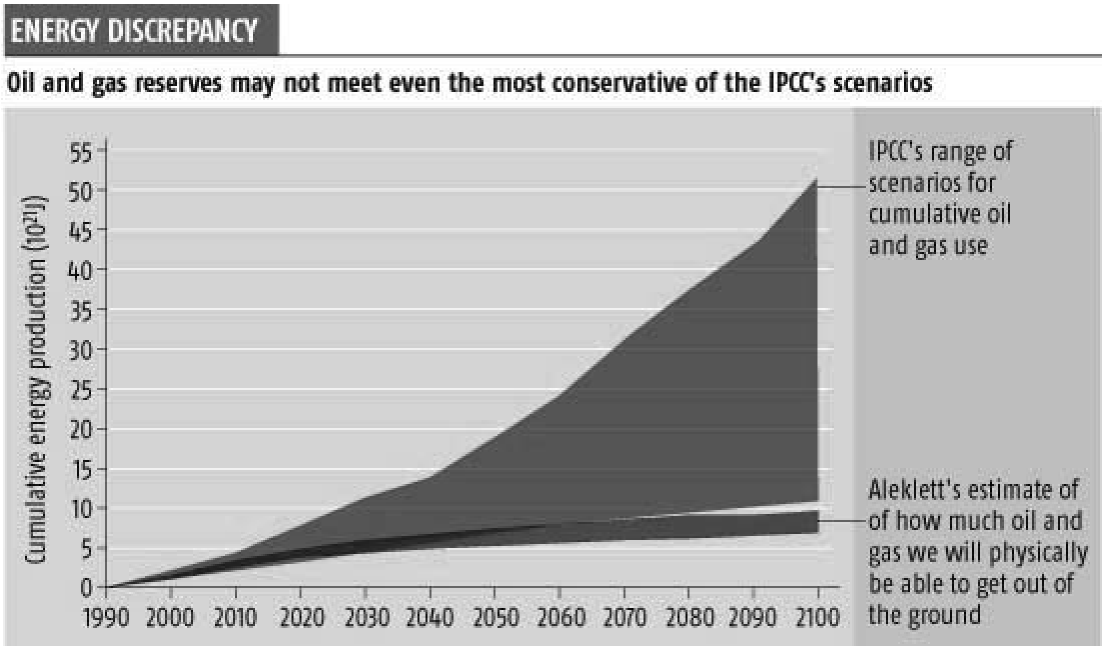
I would also like to thank Simon Snowden (University of Liverpool Management School, UK) for proofreading the paper and for the provision of feedback.

ANNEX

“Too little” oil for global warming

- *New Scientist*
- 5 October 2003
- Andy Coghlan



ENERGY DISCREPANCY

Oil and gas reserves may not meet even the most conservative of the IPCC's scenarios

IPCC's range of scenarios for cumulative oil and gas use

Aleklett's estimate of of how much oil and gas we will physically be able to get out of the ground

“Oil and gas will run out too fast for doomsday global warming scenarios to materialise, according to a controversial analysis presented this week at the University of Uppsala in Sweden. The authors warn that all the fuel will be burnt before there is enough carbon dioxide in the atmosphere to realise predictions of melting ice caps and searing temperatures.

“Defending their predictions, scientists from the Intergovernmental Panel on Climate Change say they considered a range of estimates of oil and gas reserves, and point out that coal-burning could easily make up the shortfall. But all agree that burning coal would be even worse for the planet.

“The IPCC's predictions of global meltdown provided the impetus for the 1997 Kyoto Protocol, an agreement obliging signatory nations to cut CO_2 emissions. The IPCC considered a range of future scenarios, from profligate burning of fossil fuels to a fast transition towards greener energy sources.

"But geologists Anders Sivertsson, Kjell Aleklett and Colin Campbell of Uppsala University say there is not enough oil and gas left for even the most conservative of the 40 IPCC scenarios to come to pass (see Figure).

"Billions of barrels

"Although estimates of oil and gas reserves vary widely, the researchers are part of a growing group of experts who believe that oil supplies will peak as soon as 2010, and gas soon after (New Scientist, 2 August 2003).

"Their analysis suggests that oil and gas reserves combined amount to the equivalent of about 3 500 billion barrels of oil considerably less than the 5 000 billion barrels estimated in the most optimistic model envisaged by the IPCC.

"The worst-case scenario sees 18 000 billion barrels of oil and gas being burnt: five times the amount the researchers believe is left. "That's completely unrealistic", says Aleklett. "Even the average forecast of about 8 000 billion barrels is more than twice the Swedish estimate of the world's remaining reserves."

"Nebojsa Nakicenovic, an energy economist at the University of Vienna, Austria, who headed the 80-strong IPCC team which produced the forecasts, says the panel's work still stands. He says they factored in a much broader and internationally accepted range of oil and gas estimates than the "conservative" Swedes.

"Even if oil and gas run out, "there's a huge amount of coal underground that could be exploited", he says. Aleklett agrees that burning coal could make the IPCC scenarios come true, but points out that such a switch would be disastrous.

"Coal is dirtier than oil or gas and produces more CO_2 for each unit of energy, as well as releasing large amounts of particulates. He says the latest analysis is a "shot across the bows" for policymakers."

FUTURE PRICES AND AVAILABILITY OF TRANSPORT FUELS

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Oak Ridge National Laboratory
Oak Ridge
Tennessee
USA

SUMMARY

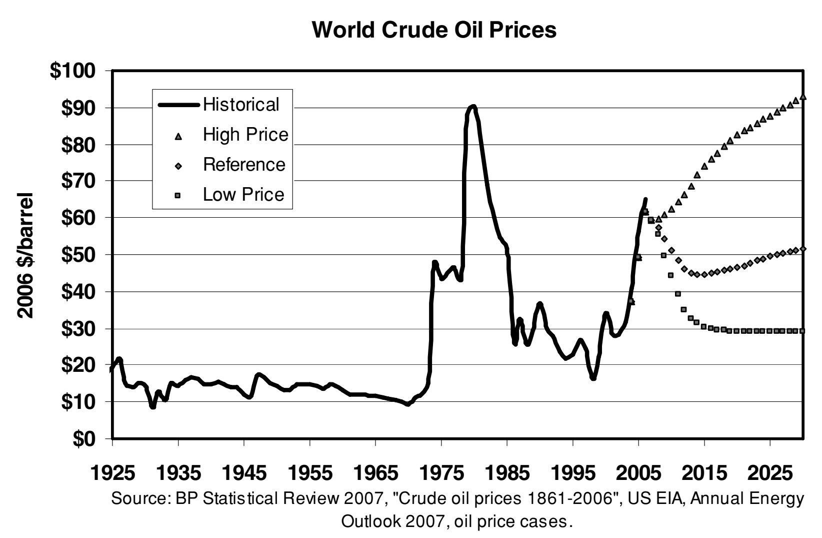
Oak Ridge, Revised October 2007

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 than conventional fuels. 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 as well as 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**



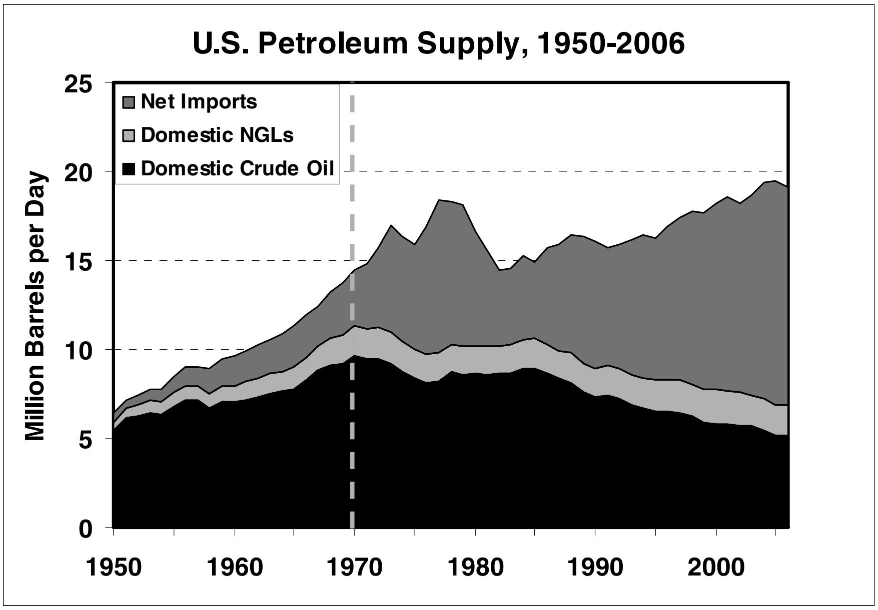
Source: BP Statistical Review 2007, "Crude oil prices 1861-2006", US EIA, Annual Energy Outlook 2007, oil price cases.

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 US crude oil output peaked in 1970, the United States was the world's largest producer of crude oil (US 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, US 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 US 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 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 US Secretary of Energy asked the US 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 US Geological Survey's median estimate of the world's ultimate resources of conventional oil (Ahlbrandt *et al.*, 2005).

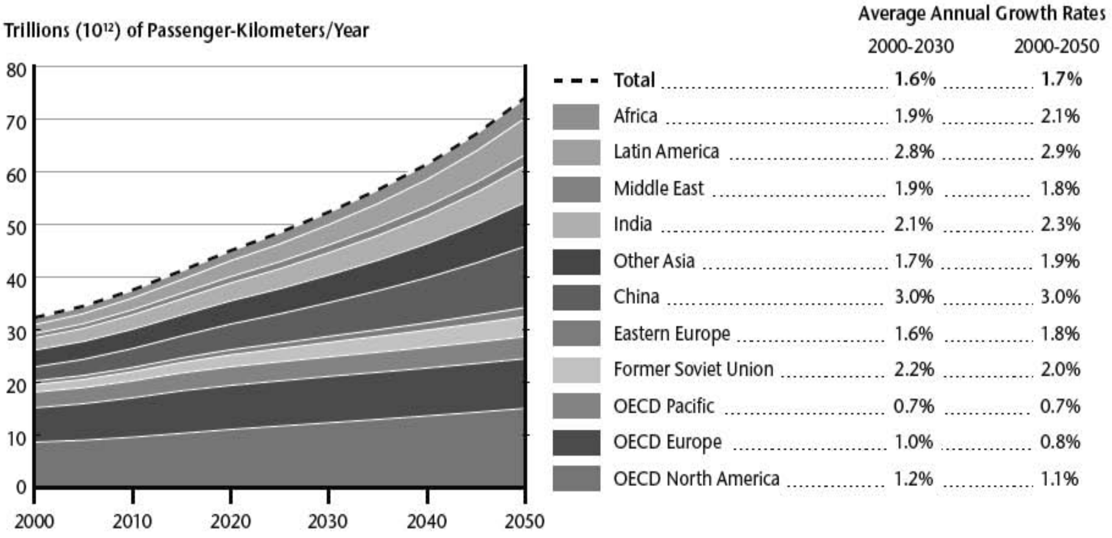
World oil demand is growing chiefly because of the continuing, slow growth in transport activity in the developed economies and the rapid expansion of motorized transport in developing economies. The IEA projects that primary oil demand will increase by 1.3% per year, from 84 mb/d in 2005 to 99 mb/d 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 US 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 kilometres 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% per year). Freight traffic is expected to more than triple over the same period, growing at an average annual rate of 2.3% per 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.

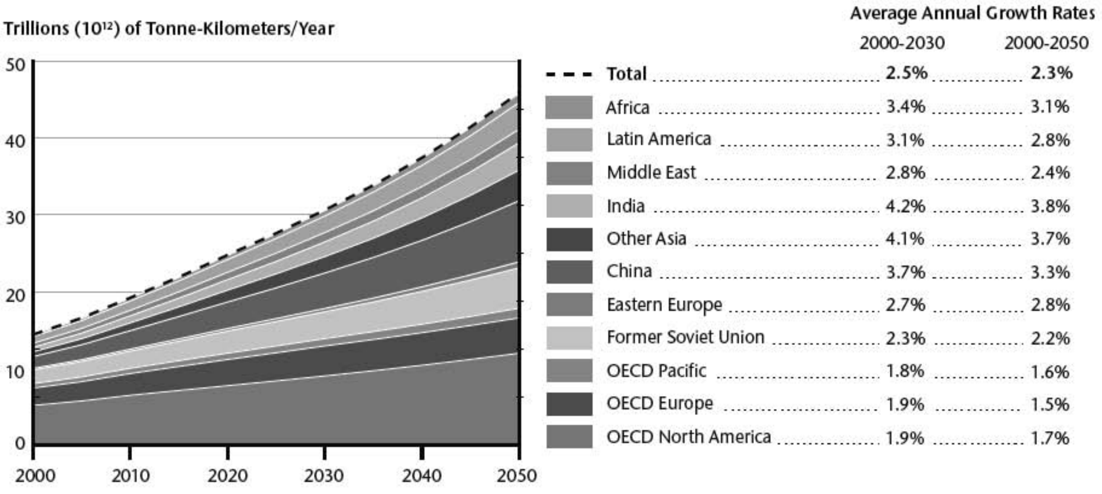
Worldwide transportation fuel use is projected to double by 2050 despite significant energy efficiency gains. The *Mobility 2030* study projects reductions in energy intensity of 18%, 29% and 29% for light-duty vehicles, heavy-duty trucks, and aircraft, respectively by 2050. The IEA (2006b, p. 253) asserts 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 litres of gasoline equivalent energy, nearly 180 exajoules, annually.

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



Source:
Sustainable Mobility Project calculations.

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



Note:
Excludes air waterborne and pipeline.

Source:
Sustainable Mobility Project calculations.

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 US, 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 its 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). Either increased oil supply must then come 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 US Geological Survey (USGS) in 2000. USGS geologists estimated the quantities of conventional oil, gas and natural gas liquids (NGLs) that 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.

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.

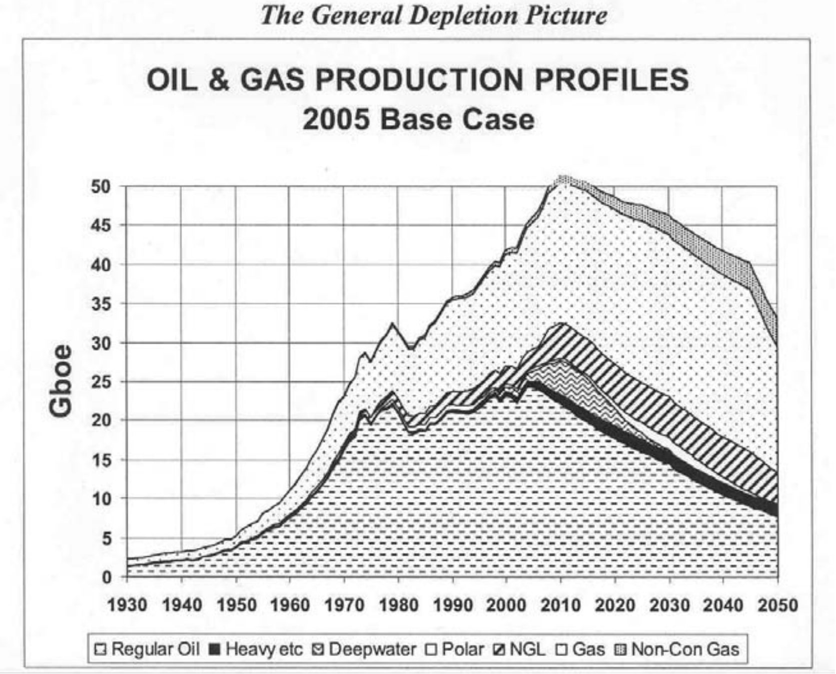
How long will the oil last? Unfortunately, dividing the estimated 2 trillion barrels of crude oil remaining by the current annual production rate of 26.5 billion barrels produces not an estimate of the life of conventional oil resources but yet another measure of their size denominated in unusual units: 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 its rate of production?" Disciples of M.K. Hubbert, a Shell geologist who correctly predicted the peaking of US 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 are they 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?

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**



Source: ASPO, 2007.
Gboe = billion barrels of oil equivalent

Government and oil 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.

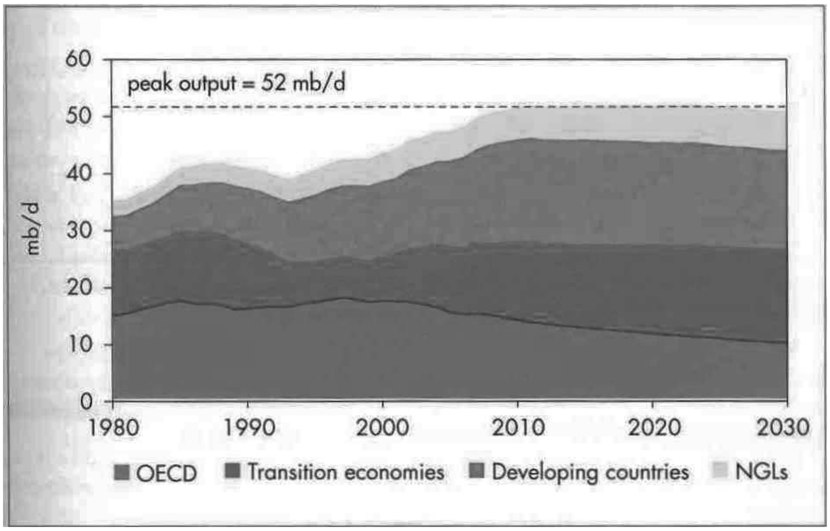
> "The concept of peak oil production and its timing are emotive subjects which raise intense debate. Much rests on the definition of which segment of global oil production is deemed to be at or approaching peak. Certainly our forecast suggests that the non-OPEC, conventional crude component of global 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 in 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).

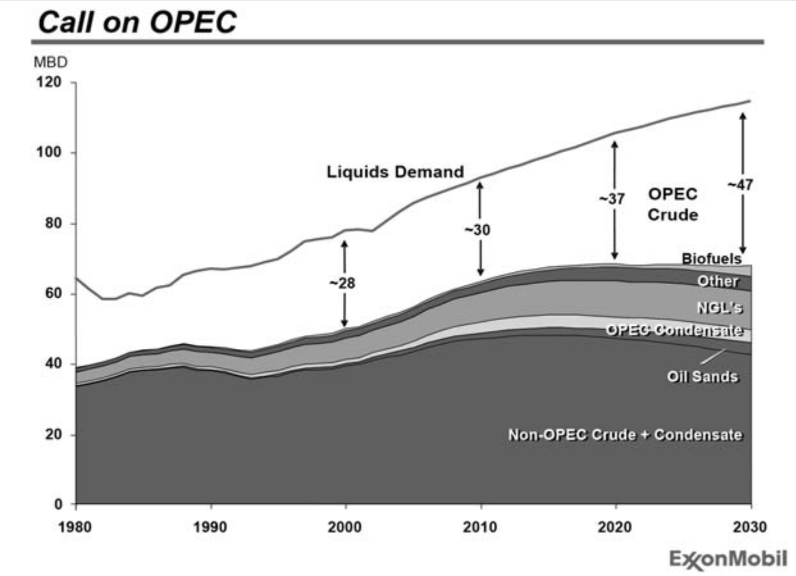
Figure 5. **Non-OPEC Crude Oil and NGLs Production**, *World Energy Outlook 2006*



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**



Source: 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 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.

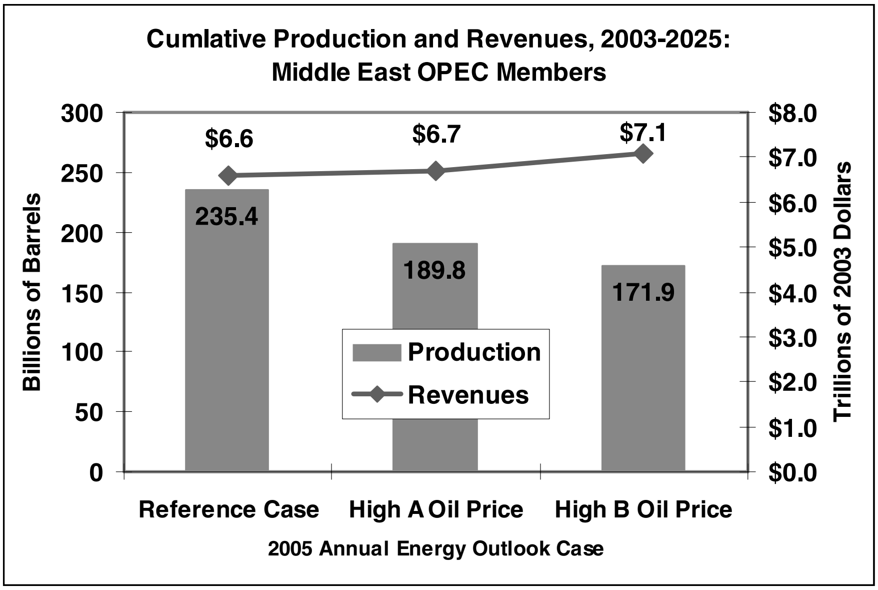
The EIA's Reference, Low World Oil Price and High World Oil Price cases are defined by differing views about: 1) the size of conventional oil resources (ultimately recoverable) and 2) the willingness of OPEC members to expand production (EIA, 2007, p. 34). The Reference case is based on the US Geological 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 the 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.

Figure 7. **OPEC Revenues at Alternative Production Levels, 2003-2025**



Source: 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 US 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.

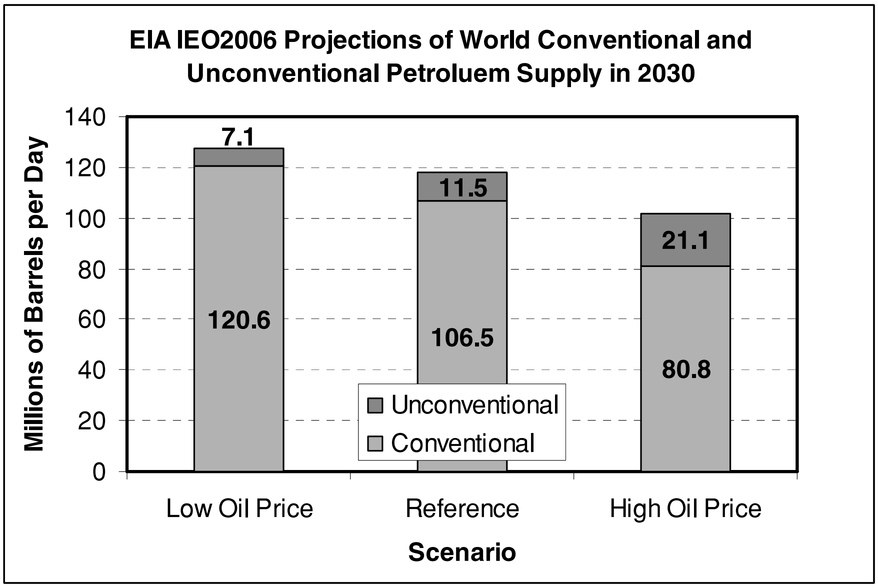
3.2 Unconventional fossil hydrocarbon resources and coal

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 2030 in EIA's high world oil price case (Figure 8).

Figure 8. **EIA IEO2006 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 coal resources are vast and could be an important source of energy for 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).

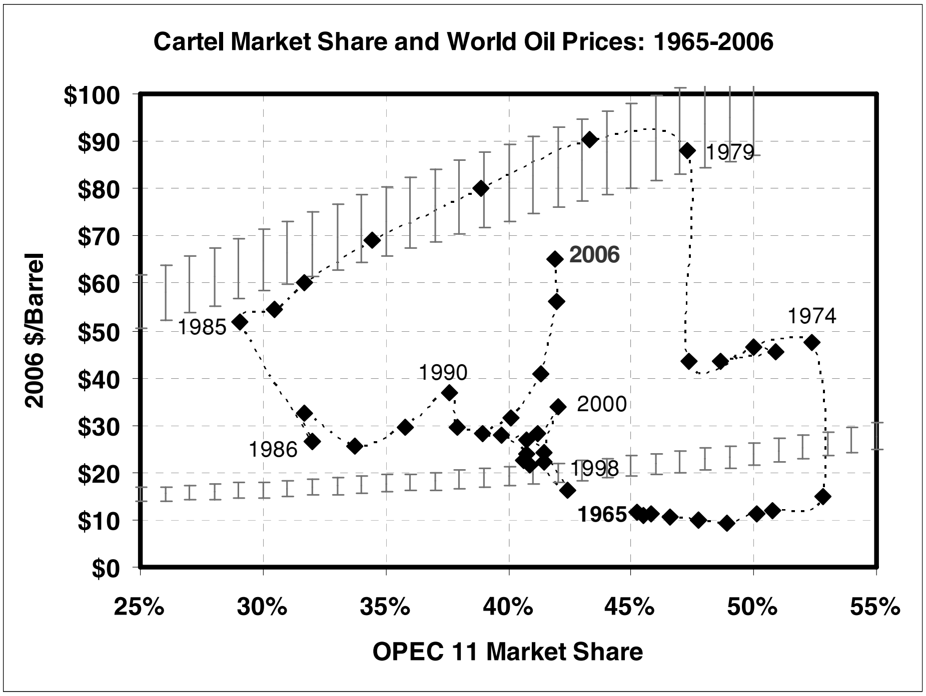
3.3 OPEC market power and world oil prices

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 annex), 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 annex 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 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 by 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**



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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 US 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 US Federal Reserve Board stated flatly 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 US 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 AND 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 litre. 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, to 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/litre, even at the high end of the range. Thus, assuming feasible CCS, the cost of coal-to-liquids transport fuels may be in the order of \$0.25-\$0.35/litre higher due to restrictions on carbon emissions.

The feasibility of carbon sequestration is by no means certain. Risks range from gradual leakage from geological 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 in 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, they will be 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 US, 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 US 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 tyres, down-weighting via materials substitution and advanced manual-automatic or continuously variable transmissions, would consume approximately half as much fuel per kilometre 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 US analyses of car size, weight and safety suggest 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 and 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 twenty 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.

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 in the order of $50/tCO$_2$, if CCS is feasible and the IPCC cost 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 in 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 that 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 that 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 US Energy

Information Administration (Greene and 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.

Figure 10a

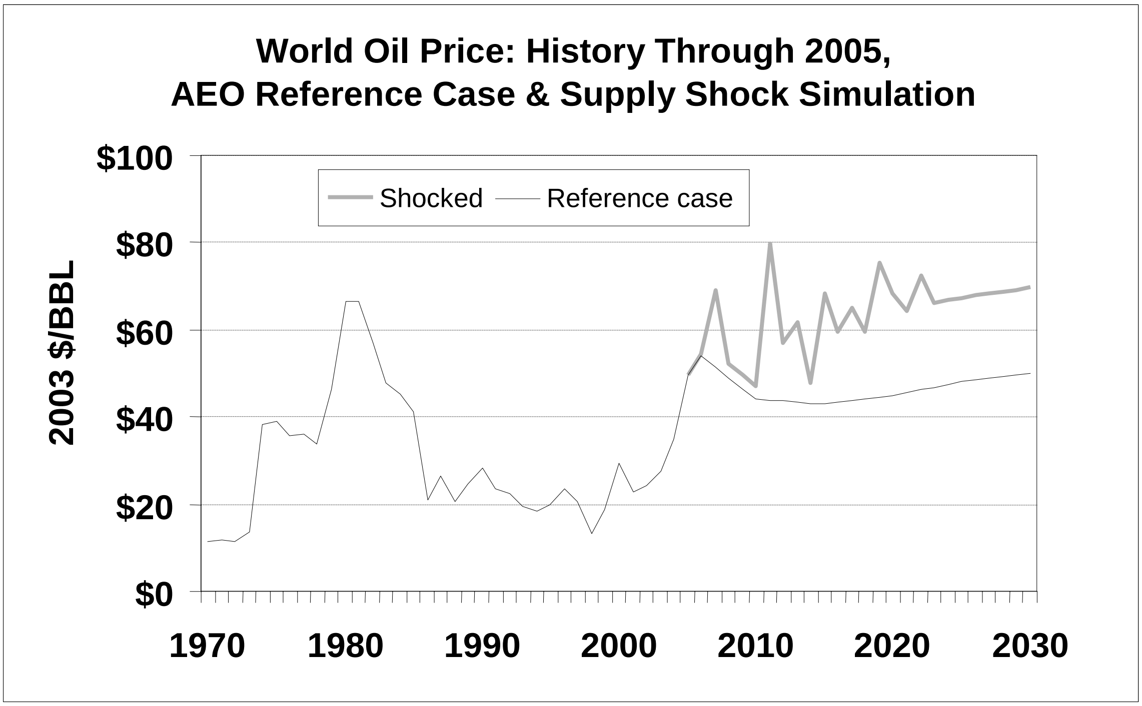


Figure 10b

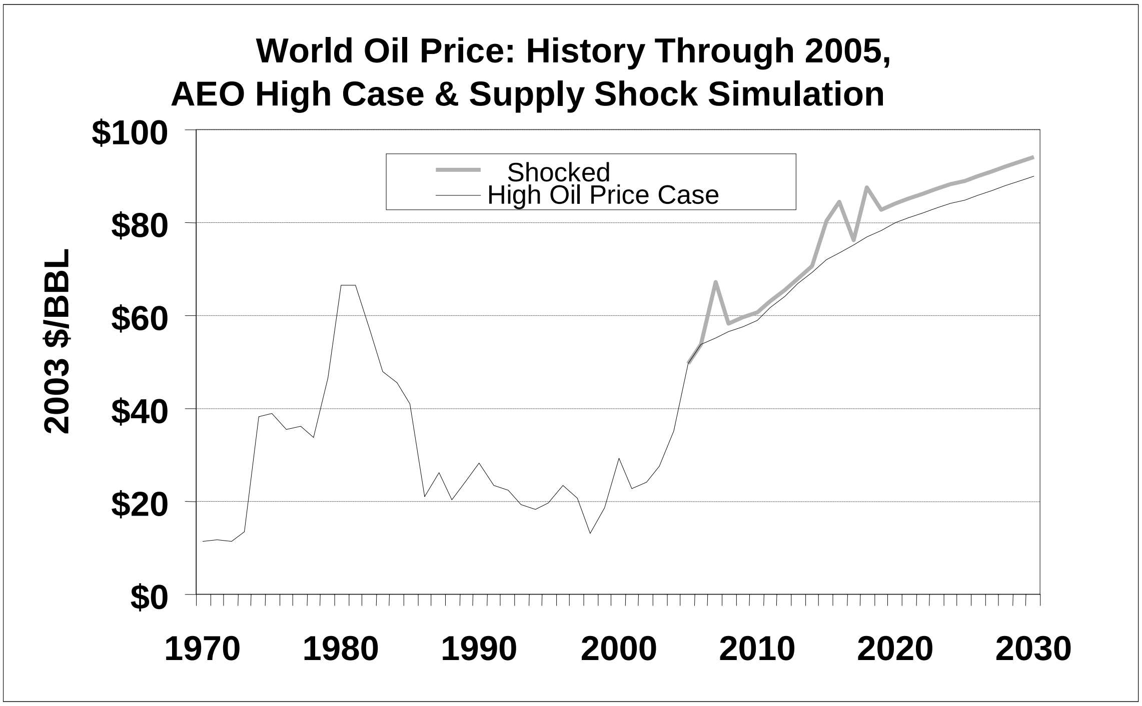
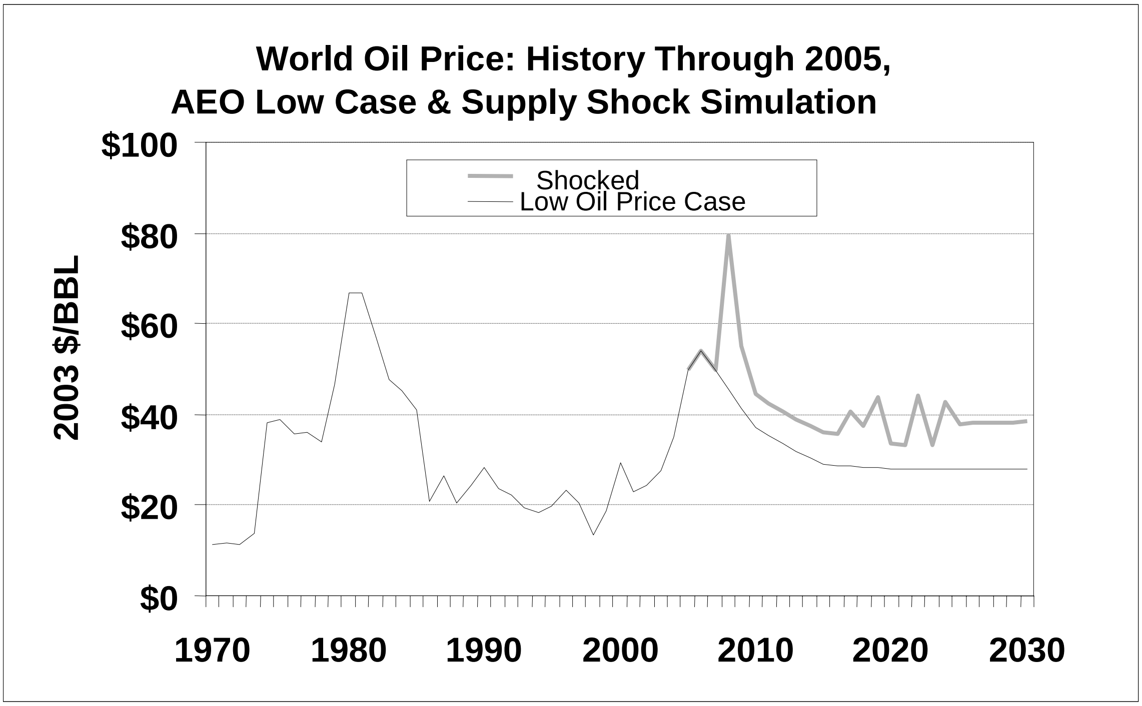


Figure 10c



NOTES

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.

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.

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

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

ANNEX:
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 $r\times100\%$ per year and, in addition, that rest-of-world supply is exogenously shrinking at $\delta\times100\%$ 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 $\delta=0$.

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.

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

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.

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

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

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.

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 that 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.

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MEDIUM-TERM OIL MARKET UNCERTAINTIES

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SUMMARY

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1. OVERVIEW

The oil market has changed dramatically over the past eight years, with prices rising from $10 to over $90/barrel. The dynamics of the industry have changed, but there is still considerable debate over whether this represents a paradigmatic shift of supply and demand conditions or is simply a result of longer term cyclical factors. Non-OECD oil demand growth is running three times faster than in the OECD, and is set to surpass the OECD in volumetric terms in the middle of the next decade. Non-OPEC supplies have plateaued over the past five years and look set to remain at such levels for the coming five years. Understanding the drivers behind these shifts gives an insight into the prospects for the coming years. However, even looking five years forward, there are many variables which could affect the outcome. These forecasts therefore provide a guide to the future, but should not be expected to project supply and demand with pinpoint accuracy. Equally important is the need to understand the uncertainties which lie behind any forecast that could change the final outcome.

This paper derives from the extensive work undertaken by the International Energy Agency for its Medium-Term Oil Market Report, and looks at the variables and forecasting uncertainties that could alter the forecast path.

1.1 Demand methodology

Our econometric demand model is primarily driven by the GDP assumptions provided by the IMF's *World Economic Outlook*, combined with a price assumption of IEA import prices (derived from the prevailing ICE[1] Brent futures curve). Using historical data, this model is adjusted to account for short-term factors (unseasonable weather variations, retail tax changes, etc.) and longer-term structural shifts (such as interfuel substitution, changes in the vehicle fleet or petrochemical expansions, and policy changes, etc.), in order to determine an underlying demand trend by product and country.

This "top-down" approach implies calculating income and price elasticities for every major product group for all countries in the world. This allows us to assess the global trends for each individual product market – which can often be very different from an assessment based on total oil demand. For example, transportation fuels tend to be more income-sensitive, while fuel oil, which is more readily substitutable, is more price sensitive.

Our demand analysis is complemented by "bottom-up" sectoral analysis, which focus on changes in end-user demand – for example, the impact of the switch from gasoline to diesel vehicles in Europe, the effects of the rapid expansion of petrochemical capacity in Asia and the Middle East, or the growing use of natural gas and coal for power generation in Europe. Although this approach provides a valuable comparison with the main "top-down" assessment, its results must be interpreted with caution. For example, will there be sufficient feedstock supply (predominantly naphtha) to sustain China's petrochemical expansion plans? Will this expansion result in a regional petrochemical surplus, leading to the closure of less efficient plants?

1.2 Forecasting uncertainties

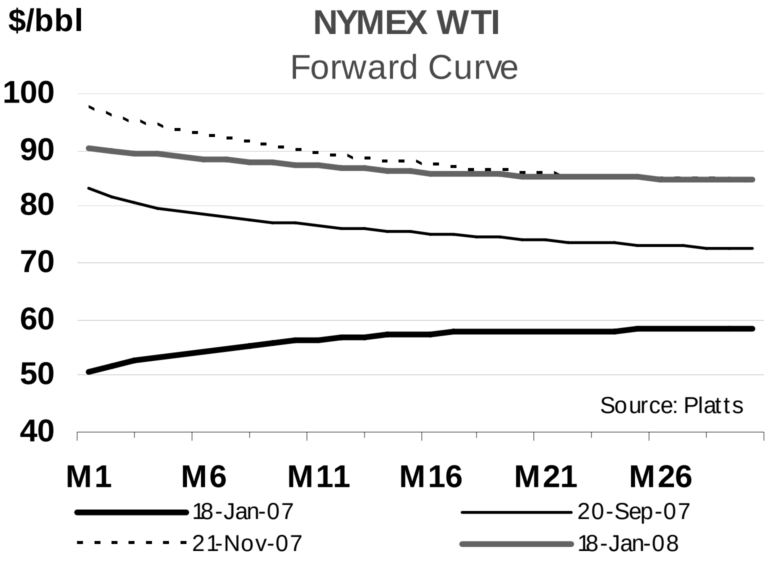
Global demand is predominantly driven by two primary forces, price and income. If the assumptions underlying those variables are wrong, then the output of the model will be affected. Similarly, the robustness of the historical data underpinning the model is important. Finally, substitution issues can work in many ways, leading to additional modelling complications.

1.3 Prices

When constructing our medium-term forecasting model, a price assumption was one of the harder concepts to incorporate. The dynamics of the oil market have changed considerably over the past five years and we are unaware of any formal price model that predicted a rise in the oil price from $25 to $90/bbl over the past four years. The seemingly robust relationship between oil stocks in the OECD and prices appeared to break down. Additional inputs, such as refining capacity, spare upstream capacity, investment flows, natural gas prices and the term structure changes between spot and forward prices, have all had an impact.

Ultimately, the decision was taken to use a price assumption derived from average IEA import prices and the futures curve. This provided the opportunity to look at future developments under current market assumptions. By definition, this also means that the rest of the model is assessed under the same conditions – i.e. it is a static model designed to highlight where current market forecasts potentially lead to imbalances. These imbalances, in our opinion, offer the greatest insight into the medium-term market direction. The medium-term forecasts are therefore not the outcome of a dynamic equilibrium model of oil supply and demand.

There is a lively academic debate over the usefulness of the futures curve in predicting market prices. Although a market-derived price allows consumers and producers to fix prices up to seven years in the future (by effectively purchasing the right to buy or sell oil in the future at a price fixed today), the only portion of the futures curve that has a strong predictive record is the refining margin derived from NYMEX crude, gasoline and heating oil futures curves, as evidenced by empirical studies. Under tight market conditions, the spot oil price tends to trade above forward months to form a “backwardated” price structure. The steepness of the curve tends to reflect the relative scarcity of spot material, and the formation is therefore generally associated with rising prices. As such, while cyclically prices may be expected to fall once a bull market has finished, a backwardated market curve shows limited explanatory insight during the rising price trend.



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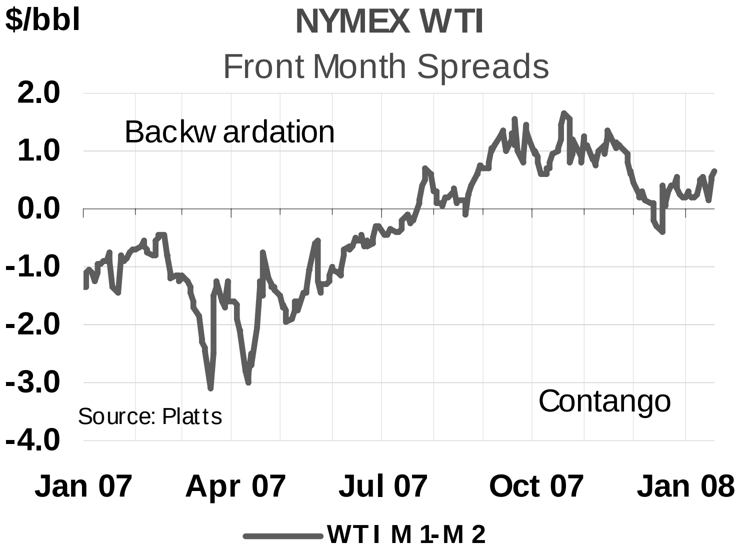

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The opposite situation is a “contango” structure, generally seen when the oil market is amply supplied and the spot price is below forward prices. Market theory shows that there should be an upper limit to the forward price rise representing the cost of storage, finance and insurance at the point of pricing. Typically, a contango structure is associated with falling prices, which again is of limited value except at the bottom of a bear market, where prices are expected to rise. However, over the course of the past four years, the average rise in oil prices has been over $12 per year, with intra-year volatility sometimes being over $20/barrel both up and down. Atypically, this rise in prices has also been associated with a contango structure for the past two years.

However, while the traditional relationship of a contango market and falling prices has been turned on its head, there remains a strong link between the spot and forward price differential and stock levels. Unusually, crude prices have been rising, despite rising stockpiles. This has led to considerable debate between analysts: has the rising crude price been a reflection of anticipated longer-term oil market tightness and the need for more investment and energy conservation? Is it a complex interaction, reflecting the mismatch between the structure of crude product demand and spare refining capacity, or merely a distortion relating to the large inflows of passive investment money into commodities?

Ultimately, by using a futures curve, the MTOMR produces a forecast that displays potential imbalances in the future that could necessitate further price shifts to achieve the necessary equilibrium outcome, rather than trying to adjust the price to induce market balancing shifts in supply or demand. Arguably, as the market has shown over the past few years, stock shifts, which are of little relevance in long-term projections, can considerably influence medium-term outcomes.

1.4 Substitution

Interfuel substitution is in essence a further price effect, but one much harder to model. The most obvious fuel shift both to and away from oil involves the usage of natural gas in the power generation sector. Unfortunately, there is no global natural gas price through which these effects can be easily modelled. As planning and construction of gas-fired power generation takes years, the structural shift away from oil is derived from an expected long term running cost advantage for natural gas. However, as long as there is fuel switching capacity or idled capacity that can quickly be brought back into service, there can be shorter-term substitutions.

While the expansion of LNG trade may lead to a convergence of prices around the world, a large number of natural gas supply contracts (in Europe and Asia) are related to oil prices. This can lead to shifts in power generation demand for natural gas that are unrelated to economic trends in gas supply and demand. Where natural gas prices are derived from a long-term moving average of oil prices, volatility in the oil price can lead to periods where there are significant differences between oil and natural gas prices. Ultimately, in these instances, US natural gas futures prices can be used as a barometer for fuel switching potential. Nevertheless, increased fuel oil demand is either related to natural gas generating capacity constraints, supply issues, or weather-related demand surges, rather than outright price shifts. Therefore, the price elasticities for fuel oil are extremely difficult to calculate and are often nonsensical, so a judgmental approach to power demand is usually required.

Emissions regulations are likely to further complicate oil demand projections, and particularly those of fuel oil use. The IEA’s *Medium Term Gas Market Review* indicated the potential for gas market tightness in key areas beyond 2010, as natural gas-fired power generation capacity expands at a level that may be incompatible with regional supply growth. Typically, short-term power generation issues are often resolved by turning to fuel oil as a temporary fuel source. Beyond 2010, however, considerable investment in refinery upgrading capacity may lead to a tightening of the fuel oil market.

With emissions regulations making it difficult to restart old coal power generation plants, there is the potential for sharp upward price pressures in both fuel oil and natural gas prices, which would be felt across the petroleum sector. With the refining industry effectively converting fuel oil into transportation fuels at that point, any increase in fuel oil demand would lead to a decrease in the supply of transportation fuels. Ultimately, tightness in natural gas supplies could lead to a tightening gasoline balance. The question that arises, therefore, is at what point (if at all) would governments decide that it is better to suspend emissions constraints to allow idled coal generation capacity, if the alternative were sharply rising oil and gas prices or power shortages.

The petrochemicals industry is another area where there can be significant inter-fuel substitution. While there are some instances where natural gas and biofuels have substituted oil product inputs into petrochemicals, substitution generally occurs between different petroleum products. LPG, naphtha, gasoil, NGLs and condensates can all be largely interchangeable. The demand for these products will be related not only to their relative price, but also to their availability, which in turn can be related to the demand for other products, available capacity and natural gas investments. Again, these differences mean that price elasticities for these products require an in-depth understanding of the sector, together with a necessarily judgmental approach to demand.

Substitution, however, is not simply an input effect. For example, significant shifts have been seen away from base metals to plastics in recent years in two key areas – construction and beverages. The popularity of the PET bottle has displaced aluminium demand from the canning industry. Pet bottles have the twin advantage of lower weight and resealability – benefits for consumer, distributor and marketer. Similarly, in the construction industry the rampant rise of copper prices in recent years has led to significant market penetration of plastics in domestic and industrial plumbing. Both examples are areas where innovation, availability and price could significantly affect oil demand patterns in years to come – particularly in the petrochemical sector. Similarly, waste management in many OECD countries is putting pressures on the use of plastics in packaging and other areas – again, an area where substitution may be induced in a relatively short period of time.

1.5 Subsidies

A further area of forecast uncertainty is fuel subsidies. Price and income effects tend to be larger in developing economies, but with state-administered prices prevalent in a large number of populous non-OECD consuming countries, the spot price is not necessarily reflective of local market conditions. Indonesia provides a good example of the impact and uncertainty caused by heavy oil subsidies, which at current prices are expected to cost in excess of $5bn/year. An attempt to raise oil prices in 2005 led to significant social unrest, and had to be partially undone shortly afterwards. As prices rose, there were significant swings in local demand, but with smuggling in the region commonplace, it was difficult to determine how much of the demand swing was related to pre-emptive local stockpiling and reduced smuggling and how much final consumption was lowered. The rapid rise in oil prices in 2006 meant that subsidies were effectively re-introduced. Indonesia is perhaps a micro-study of regional uncertainty, and the prevalence of (lesser) subsidies in China and India means that price effects could be much larger at some point in the future, therefore distorting demand growth. The Middle East is a further key demand growth area where fuel prices are heavily subsidised. Again, although domestic pressures to liberalise prices are less (due to rising oil incomes), the policy shifts could alter the path of demand via price effects.

1.6 Economic growth

The IEA demand forecasts are based on GDP projections derived from work undertaken by the IMF and OECD. They are subject to forecast uncertainty, which has been covered extensively by the agencies themselves. At the present time, both agencies warn there are considerable uncertainties to the downside, which confer similar downside risks to oil demand. From a longer-term perspective, unless the trend in GDP growth alters dramatically from the projection, cyclical swings are likely to even out. In a five-year time horizon, a recession or boom could considerably alter the projected outcome.

Immigration is a further issue to consider. The expansion of the EU has led to widespread worker migration, leading to rapid population expansions in wealthier countries. With oil income elasticities being driven by income per capita changes, shifts in migration could have an important impact. In the UK, for example, our assumption of relatively static population growth may be too low. Migrant worker growth may have added several million to the UK population over the past few years, while one study group projected that the higher birth rates of migrant workers could lead to a significant population increase in the next 20 years. Such shifts in worker migration could raise per capita GDP, and could distort growth rates. Similarly, some studies have attributed recent growth in US gasoline demand to shifts in migrant workers. Ultimately, though, in the case of many countries we may have to wait ten years for accurate census data on the population to provide a benchmarking snapshot.

1.7 Data

Turning to forecasting uncertainties, in addition to those surrounding future economic growth and oil price evolution (notably at the retail level), the predictive power of any demand forecast is largely dependent upon the availability and quality of the historical data underlying the projections. In countries where the collection of detailed oil statistics is still in its early stages, both data (and revisions) may be inaccurate. This may lead to an over- or understatement of demand, thus distorting the calculation of income and price elasticities upon which the forecasting model is based. In the case of Asia, for example, revisions have tended historically to be upward, suggesting that current demand may be understated. Moreover, many non-OECD countries do not include stock data, obliging analysts to estimate demand on an ‘apparent’ basis.

Supply-side data is far from perfect, but historically, the larger revisions have come from the demand side. This is partly due to the fact that in many areas, national supply-side data can be double-checked with results from oil companies. In many cases in non-OPEC countries, supplies can be aggregated independently on a field-by-field basis. However, that is not the case for all countries. A lack of field data and a lack of detailed and consistent methodology for reserve reporting makes estimates for rates of decline in production difficult in many regions.

Similarly, it is clear that at times, politics have played a role in reserve estimation in some OPEC countries. During the late 1980s and early 1990s reserve levels within the producer group had an influence on daily production targets. At that time, there seemed to be an increase in proven reserve levels, more to maintain market share than through technological innovation or discovery.

Demand, however, typically relies on accurate reporting from the refining, distribution, stock-holding and import/export sectors to central government data collection. The Joint Oil Data Initiative (JODI) is a welcome attempt to improve data availability and quality. Nevertheless, despite the efforts of its members (IEA, OPEC, APEC, UNSD, OLADE and Eurostat), the statistical balancing item in the Oil Market Report (“miscellaneous-to-balance”) has been rising in recent years. There is clearly some way to go – the more so if the miscellaneous-to-balance item turns out to be due to under-reported demand.

Understandably, therefore, much of the data uncertainty focuses on non-OECD countries, and in particular, the major growth regions of Asia and the Middle East. Given China's status as the world's second largest oil consumer and rapid oil demand growth, the fact that its energy balance is subject to close scrutiny is only natural. While data has improved – quality is significantly better than many other countries with a similar level of GDP per capita – China still needs to take several key steps: 1) release primary (refinery level) commercial and strategic stock data; 2) survey "teapot" refinery activity; 3) revise data, particularly that pertaining to trade figures; and 4) explain why Chinese refiners achieve a volumetric processing loss, while European and US refiners with similar equipment achieve refinery gains.

These data inconsistencies – probably due to the lack of free-market pricing throughout the supply chain, which provides incentives to distort data reports – make it difficult to assess China's oil demand. For example, news reports suggest that teapot refiners are supplied with domestic crude, which is unreported on both the supply and demand side – possibly amounting to around 150-250 kb/d in 2007. Similarly, customs data has sometimes shown no crude exports in a particular month, despite evidence of effective loading and sailing of cargoes.

The IEA estimates Chinese demand on the basis of refinery output plus net product imports, adjusted for direct crude burn and the use of teapot refineries. However, it could also be calculated by adding domestic crude production, net crude and net product imports. This latter methodology, though, does not enable the disaggregation of demand on a product-by-product basis and tends to overestimate demand if stock-building is significant. Having to choose between both methodologies – which by definition include some arbitrary assumptions and hence can lead to different results – we believe the first one, during a period where China is building strategic oil stocks, is perhaps more accurate, since it allows us to track each product.

India, meanwhile, has the potential to see a surge in energy demand, and presents data reporting issues which complicate the understanding of regional energy balances. Indeed, local analysts suggest that coastal imports outside of main consuming areas may be under-reported, therefore leading to a lower recorded demand. In addition, the widespread adulteration of diesel-based fuels can lead to distortions of inter-product demand. Last but not least, there is no reliable of commercial stock data.

In the Middle East, reporting qualities vary. While data from certain countries, Saudi Arabia in particular, is very comprehensive on the demand side, in others, demand data collection is in its infancy. Large price subsidies lead to extensive smuggling.

1.8 Biofuels

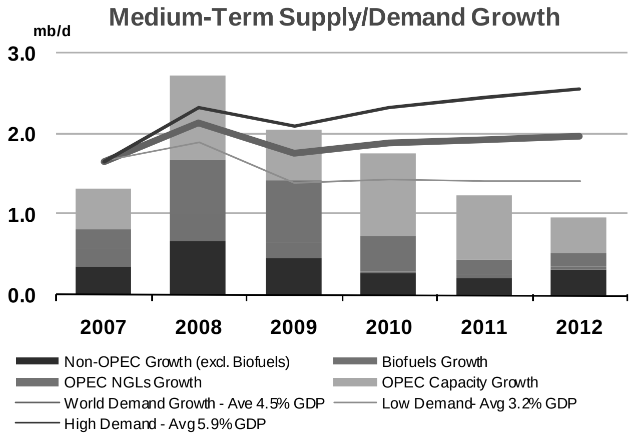
Automotive biofuels represent a further uncertainty, although it is rather contentious whether or not they should be regarded as a demand-side uncertainty. From the perspective of demand forecasting, biofuels are only significant in that the lower volumetric energy content of ethanol and biodiesel supplies needs to be accommodated in our projections. However, biofuels are important with regard to the petroleum-liquids they displace.

Over the medium-term, biofuels supply and demand will broadly match, but this is not necessarily the case over the short term. Automotive biofuels production capacity is expanding rapidly, sometimes at a rate faster than the mandated level refiners are required to blend. This could lead to short-term imbalances. In addition, the rapid expansion of biofuels production capacity is tightening feedstock markets and therefore raising their price, posing questions over whether sufficient feedstocks will be available at an economic rate to meet capacity growth projections. Given these caveats, our biofuel supply projections are around 1 mb/d below planned capacity expansions by 2012.

2. SUPPLY-SIDE UNCERTAINTIES

The MTOMR projects strong non-OPEC liquids (crude, condensate, NGLs and biofuels) supply growth in 2007-2009, appearing to recede thereafter as the slate of verifiable investment projects diminishes. Total non-OPEC liquids supply growth to 2012 is pegged at 2.6 mb/d. The report estimates that around 3 mb/d of new production is needed each year to offset the effects of decline. This equates to net oilfield decline rates averaging 4.6% annually for non-OPEC and 3.2% per year for OPEC crude. Aggregate levels mask much sharper declines in a 15-20% per annum range for mature producing areas and for many recent deepwater developments. Further, our supply-side estimates incorporate a new 0.4 mb/d contingency factor, reflecting a tendency for unscheduled field outages.

Supply-side uncertainty is further exacerbated by increasing instances of resource nationalism and geopolitical risk, constraining the ability of the industry to expand output. Upstream construction, drilling and service capacity will remain stretched for some time, leaving forecasts prone to slippage, due to cost over-runs and project delays. On balance, these above-ground risks are seen as greater than those posed by resource depletion and other below-ground factors. Overall, this leads to average non-OPEC supply growth of 1.0% between 2007 and 2012, 0.4% below the growth seen in the previous seven years and roughly half the rate of global demand growth projections.



Ultimately, there are the natural resources to boost output in the medium term, but there are considerable questions about whether the above ground access, service sector resources and IOC investment plans will deliver. With this in mind, substantially higher cash returns to shareholders stand in curious contrast to growing upstream supply tightness and essentially unchanged exploration and production (E&P) effort. Nominal E&P expenditures are up, but higher costs have eroded their purchasing power commensurately. However, it is clear that there are other issues at work.

In particular:

- Access and contractual conditions (even in OECD countries) are deteriorating.
- Hurdle rates for upstream investment may be too conservative (development costs have moved higher, albeit there are indications that cost inflation may be stabilising).
- Labour, equipment and service sector constraints may reduce the potential for expansion of the project base, at least through 2012.
- The rise of consumer-country NOCs and independent exploration companies is eroding the market share of more risk-averse IOCs, which endured years of lower returns after the oil price collapsed in the mid-1980s.

2.1 Project slippage

Project slippage is a major issue for supply-side projections. In the five months between the publication of the February MTOMR update and the 2007 MTOMR in July, over 3.2 mb/d of new projects in the 2007-2011 period saw their timing slip, emphasizing the scale of the problem. Slippage varies between two and 36 months, but is typically around six months. Given the extent of the problem, project timing assessments have been dealt with more aggressively, particularly with those where delay is most likely. Nonetheless, shortages of labour, raw materials, fabrication and drilling capacity and transport infrastructure may continue to undermine output growth for some time.

2.2 Decline rates

An average global decline rate is a useful rule of thumb, but one which can be over-used. From a field by field forecast, it is clear that decline rates can vary hugely even between fields in similar locations. There is a constant ebb and flow of fields entering decline, offset by others where decline is reversed by the application of EOR or satellite developments.

A proxy can be calculated by comparing net change in non-OPEC supply for 2007-2012 and gross capacity additions. The implied net non-OPEC decline rate for baseload production is around 4.6% per year. This covers not only fields in decline, but also older supply which is at or approaching plateau. With net decline from OPEC assumed at 3.2% per year, this gives a global annual decline of 4%, suggesting that 3.2 mb/d of new production must be found each year just to stand still. Moreover, this net global decline for existing assets masks fairly aggressive assumptions for parts of the OECD and for deepwater projects elsewhere. Development schedules for the latter can show rapid ramp-up followed by abrupt annual decline in a 15-20%-plus range.

Decline rates clearly hold the potential for significant oil supply forecast uncertainty. Our derived net decline of 4.6% per year results in non-OPEC oil supply (excluding biofuels and processing gain) in 2012 of 48.8 mb/d. Increasing that decline rate to 5% would net 875 kb/d off the total, and a range of decline rates from 2% to 7% swings 2012 non–OPEC supply by 11 mb/d in total.

Without minimising the importance of this variable, particularly given a shortage of comprehensive field-specific production and reserves data, our analysis suggests that variance from the original non-OPEC forecast in recent years has not primarily been due to understatement of field decline rates. Rather, we believe that project slippage, weather, and unplanned production stoppages for technical, economic and geopolitical reasons, have been, and will continue to be in the next five years, the main risk factors. Put another way, while we continue to monitor and actively adjust for shifts in field and aggregate decline, we see above-ground risks more prevalent, for now, than below-ground risks.

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). As overall non-OPEC liquids capacity increases, this plateau reduces the share of non-OPEC conventional crude supply from 77% in 2000, to 74% in 2006 and 67% in 2012.

While there might be a temptation to extrapolate this trend, citing a peak in conventional oil output, a degree of caution is in order. Firstly, the concept of “conventional” oil changes with time, technology and economics. In the early 1970s, much offshore production was deemed unconventional, but this portion of global supply has since grown to account for 30% of the total. Evolving economies of scale and infrastructure development could do the same for GTL, oil sands and ultra-deepwater reserves in the future, shifting today’s unconventional resource into tomorrow’s conventional supply category. Moreover, rapidly-growing condensate and NGL supply is scarcely “non-conventional” in a technical sense now.

We also note that for certain regions, notably the FSU and West Africa, the turn of the current decade is likely to mark a hiatus in crude supply growth. Strong growth is expected to resume here towards the middle of the next decade. Whether this will be sufficient to offset the declines expected for mature OECD crude supply, preventing overall decline for non-OPEC, is less easy to predict.

Finally, we note that focussing on non-OPEC crude alone is a rather selective way of considering the sustainability of global oil production. Peak or plateau production is frequently taken as shorthand for impending resource exhaustion. While hydrocarbon resources are finite, nonetheless issues of access to reserves, prevailing investment regime and availability of upstream infrastructure and capital seem greater barriers to medium-term growth than limits to the resource base itself. Critically, our belief that above-ground factors rather than resource constraints are the key impediment to capacity expansion holds out the possibility that the recent slowing of capacity growth could be reversible.

3. INVESTMENT

3.1 Prices

Over the very long term, the economic threshold at which oil companies invest in upstream projects is likely to reflect prevailing oil prices. However, the extreme constraints in the oil services sector have led to rampant cost inflation. Exploration and Production budgets, while expanding rapidly, have therefore failed to deliver a proportional increase in E&P activity. While we believe that this is a cyclical phenomenon, related to labour and equipment shortages and rising commodity prices, it is not a situation that leaves itself open to modelling. Therefore, on the supply side, our forecasts are based on the premise that the spot oil price remains above the marginal cost of production for the medium term, therefore encouraging the recent increase in E&P activity from the low levels seen for much of the previous fifteen years. However, while it is clear that strong investment will be required over the longer term, medium-term investment decisions may be subject to cyclical industrial and economic effects.

3.2 Operating environment and constraints

Net supply projections are the result of "push and pull" between various factors, which clearly vary over time and often require subjective judgement. The MTOMR characterises the upstream operating and investment environment for 2006-2011 as follows:

1. Rising crude oil price assumptions employed by operating companies;
2. Increasing spending and activity levels;
3. The expanding reach of consumer country NOCs;
4. A declining trend in exploration expenditure as a share of IOC total spending;
5. High costs and tightness in construction, drilling and service capacity;
6. Correspondingly, a tendency for new upstream project delays;
7. A compounding impact of delays to new pipeline and gas processing capacity;
8. Proliferating geopolitical risks and barriers to oil company access.

Arguably, the first three factors could accelerate the pace of expansion in non-OPEC and OPEC supply. However, the balance of risks deriving from factors 4-8 lies heavily on the downside and would seem to argue for slower growth in global production capacity relative to historical trends.

These trends are clearly changing. For example, NOCs and governments are broadly budgeting for an average economic threshold of $45/bbl (versus $35/bbl a year ago), with international company and independent producer price assumptions levelling off close to $55/bbl. However, in some cases, new projects are still being tested at prices down to as low as $35/bbl. Clearly this leaves room for a growing portfolio of feasible projects with current oil prices over $90/bbl.

With rising prices, spending levels have increased. Industry spending surveys by Lehman Brothers and Citigroup suggest ongoing growth in upstream activity, notably outside of North America. Increases in expected capital expenditure in 2007 lie in a 10-15% range, with similar growth for 2008. However, many of these spending increases have been mitigated by rising upstream development and service sector costs.

In many ways, parts of the current supply cycle stretch back to OPEC supply management in the 1970s and 80s, which led to a sharp increase in OPEC spare capacity as market share was eroded by expanding non-OPEC supplies. The resultant supply overhang helped to keep prices relatively low, cyclically prompting IOCs to curb exploration, outsource service-sector roles and cut research and development. OPEC spare capacity was reduced, which meant that when the 2004 demand surge hit, the industry was left with few resources with which to respond.

It takes time to rebuild such capacity, and while high wage rates are attracting more engineers into the field, labour constraints are unlikely to ease significantly into the next decade. But it has to be recognised that this is not simply an oil-related issue. Production expansions of many natural resources are being constrained by similar factors. Equipment tightness is prevalent in many industries, and particularly in other energy sectors. Silicone shortages are limiting the expansion of solar panels, wind power generators are suffering from turbine shortages, and base metal prices are at record highs.

Cost inflation for raw materials, service and drilling capacity shows some signs of moderating, although industry consensus points to a levelling in upstream costs rather than a substantial fall. Healthy spending increases have therefore largely been absorbed by double-digit inflation, limiting any automatic feed-through of high prices into incremental discoveries and production. The rise in exploration’s share of upstream spending has been modest, and company reserve replacement rates remain weak, despite sustained high prices. This can be partly explained by access and regulatory uncertainty; in turn, partly related to a spate of resource nationalism.

Drilling indicators for oil remain positive. While there was a sharp decline in drilling activity in 2Q07 this was largely due to a collapse in Canadian natural gas drilling due to weaker gas prices. It is estimated that deepwater drilling capacity will remain constrained for another 18-24 months before substantial new capacity is activated. However, given that much of the projected increases in production are seen coming from the likes of Brazil, GOM, northern Russia, the Caspian and West Africa, the potential for additional slippage clearly compounds supply-side risks.

Delays in natural gas expansion are another factor that can be added to the list of potential forecast risks. For the Middle East and Russia, the IEA’s Natural Gas Market Review has identified insufficient upstream investment. This undermines not only natural gas liquids (NGL) supply, but also oilfield reinjection of associated gas, potentially impeding crude oil production rates. That said, as producers recognise potential future shortages in gas for domestic or export markets, so efforts to boost supply by cutting gas flaring and transmission losses should intensify.

The price signals are there but service sector capacity will take time to expand and, until it does, the market will be slow to respond. Even when this cycle has ended, there needs to be sufficient access to reserves to prompt a supply response. Further, the price incentives need to be high to persuade oil companies to take the significantly higher risks of exploration.

3.3 OPEC supply

In the MTOMR, OPEC producers are expected to add a net 4.0 mb/d to installed crude capacity during 2007-2012. The years 2008 and 2010 see particularly strong growth, when new project start-ups drive OPEC capacity higher by over 1.0 mb/d in both years. The forecast takes account of new capacity investments and net decline from older fields (decline rates are assumed to range from 1-5% per annum for onshore fields in the Mideast Gulf, through to 12-15% p.a. for deepwater fields). Overall, net decline for the group as a whole averages 3.2% annually, lower than the 4.6% evident from the non-OPEC forecast. This reflects in part the predominance of lower-decline onshore and shallow water production in the total (although deepwater production from Angola and Nigeria is taking on greater importance). OPEC therefore faces the task of replacing some 1.1 mb/d each year just to sustain capacity at existing levels.

Political and security issues also confer considerable risk to the supply forecast. The MTOMR assumes limited growth in Venezuela, Iran and Iraq, while in Nigeria a portion of long-term outages have been assumed to continue to reduce effective spare capacity. Changes to current conditions are difficult to predict, but it is fair to argue that a resolution of security issues in Iraq and Nigeria could result in a significant expansion in OPEC capacity.

Looking at OPEC crude additions for 2006-2012 tells only half the story for potential capacity growth. Gas liquids (ethane, propane, butane and pentanes from gas processing plants plus field gas condensates) are expected to rise by +2.2 mb/d (+7.8% pa) and take potential OPEC NGL supply to 7.1 mb/d by 2012. The rate of increase matches growth evident during 2001-2006, as attempts to boost natural gas utilisation and to reduce flaring continue.

While there is considerable uncertainty over the level of OPEC reserves and decline rates, as great an issue for projected oil market balances in the coming decade is how OPEC countries choose to manage their reserves. What will a country decide is its optimum production rate? There have been suggestions that Saudi Arabia, for example, will limit its crude supply expansion to a maximum of 15 mb/d. Regardless of how China or India’s future car pool is calculated, and what level of demand growth is implied, quite simply, it will not materialise if the supply is not there in the short- to medium-term.

4. CONCLUSION

Considerable forecasting risks remain on both oil supply and demand. Some of these risks can be better understood by improvements to data quality and coverage. Improved transparency will not augment supply, but it can help to improve the robustness of supply-side projections. However, arguably some of the largest uncertainties facing the oil world stem from non-oil data issues.

On the demand side, the rate of growth of oil consumption depends heavily on the rate of economic growth in highly populous developing countries such as China, India, Indonesia and Brazil. There would be a considerable difference to outcomes if Chinese economic growth were to stall, rather than continue growing at its current 10% annual rate. Similarly, these countries will eventually reach a point where growth rates moderate, thus slowing demand-side pressures.

Demand may also be constrained by an accelerated policy effort to reduce emissions. Policy and prices can alter the speed at which technological innovations occur and are incorporated.

But demand projections can only be realised if there is the supply there to meet them. National resource management policy is perhaps the hardest area to forecast. At what point a country decides its extraction rate is optimised will depend upon many factors, including prevailing price levels and the resource base. Security and political shifts can result in this factor becoming a moving target. Ultimately, though, even if supply constraints are less than envisaged, the demand potential from emerging economies is very significant, and in the foreseeable future there is little prospect of a significant shift away from petroleum-based fuels in the transportation sector. Whether constraints are derived from the supply or demand side of the equation, environmental considerations are a further reason to justify the need to prepare for a constrained transportation fuel market – even if the fuel is there, there are reasons we may not wish to use it.

NOTE

1. The New York Stock Exchange's Intercontinental Exchange. ICE's energy futures business is run by its London based subsidiary, ICE Futures Europe.

LONG RUN TRENDS IN TRANSPORT DEMAND, FUEL PRICE ELASTICITIES AND IMPLICATIONS OF THE OIL OUTLOOK FOR TRANSPORT POLICY

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ABSTRACT

This paper discusses the role of transportation in policies to address energy security and climate change. It focuses on three elements: the impact of energy prices on transport demand, the potential contributions of the transport sector to energy policies, and the interaction between energy and other policy concerns in transport. Transport is relatively unresponsive to broad-based price signals, in particular to changes in prices of fuels, but nevertheless there is considerable scope to improve the fuel efficiency of vehicle fleets. As a result, we should not expect energy policies to trigger dramatic changes in the nature of transport systems. Furthermore, this unresponsiveness suggests that it is relatively costly to reduce energy use in transport, and thus that efficient policies will probably not extract as much energy saving (in percentage terms) from transport as from other sectors. Reducing energy use in transport can be done with price incentives or with regulatory measures. But if reducing climate change is a primary goal, measures that mandate conservation need to be accompanied by others that make fossil fuels economically unattractive – for example broad-based carbon taxes. Otherwise, fossil-fuel reserves will remain economically usable and therefore will constitute a future source of carbon dioxide emissions. We argue that other transport problems, notably congestion, local air pollution, and accidents, are associated with considerably higher marginal external costs than are climate change and energy security. It follows that policies to deal directly with these other problems deserve high priority, regardless of energy policies.

SUMMARY

Irvine and Paris, December 2007

1. INTRODUCTION

Recent years have seen the re-emergence of public debates on the desirability of managing energy consumption and on the effectiveness of various ways of doing so, in transport and other sectors of the economy. The impetus for increased interest in energy issues is twofold. First, oil is a prime source of energy, so that high and volatile oil prices and increased dependence on oil imports have strengthened concerns regarding energy security. Long term projections for oil prices are on the rise. For example, in 2000 the International Energy Agency used a price of $33/barrel for its baseline projection for 2030 (prices of 2005); in 2004 the figure was $40, and in 2005 it had risen to $55, reflecting a concern that higher oil prices are not a transitory phenomenon.[1] The second impetus is a growing consensus that the expected costs of climate change warrant measures to reduce greenhouse gas emissions, although just how quickly remains controversial (*e.g.* Arrow 2007, Schelling 2007).

The goal of this paper is to assess three factors: the impact of expected higher energy prices on transport demand, the potential contributions of the transport sector to energy policies, and the interaction between energy and other policy concerns in transport. Our focus is mostly on road passenger transport because it is a particularly large energy consumer and is often targeted for energy policies.

Section 2 starts with a review of past trends and projections for the future. Nearly all sources suggest continued strong growth in transport demand everywhere, especially in developing countries like China. This demand growth is part of the reason why oil prices have increased; but higher prices so far have not tempered growth much because their effects have been swamped by those of population and income.

Section 2.4 provides a more analytical perspective to determine the main factors driving energy demand in road passenger transport. We review recent econometric evidence, especially for the US, paying particular attention to studies that distinguish explicitly the components of fuel use (vehicle stock, average vehicle mileage, and average fuel economy). This review confirms that income is a key driver of transport demand; fuel prices matter as well, but less so. In addition, the impact of the fuel cost of driving, both on the demand for driving and on the demand for fuel, appears to decline as incomes rise. A consequence is that the impact of fuel prices on fuel demand works increasingly through fuel economy improvements rather than through reductions in the amount for driving.

A broad conclusion from section 2 is that the elasticity of demand for oil will very likely decline. A consequence is that fuel taxes would need to increase more strongly in order to curb fuel consumption by a given amount. This does not affect the economic case for fuel taxes over alternative policies, but it does affect their political feasibility. When high fuel taxes are not politically feasible, then regulations of fuel economy become more attractive. In this sense, lower elasticities are “good news”, as the increased driving resulting from the lower fuel cost of driving caused by better fuel economy – the so-called “rebound effect” – is limited; this of course enhances the effectiveness of fuel-efficiency regulations in achieving their objective of reducing fuel consumption. So, from the perspective of energy security, policy responses that mandate improved fuel economy seem to make sense. But if the goal also is to reduce greenhouse gas emissions, such regulations probably should be complemented by fuel or carbon taxes, because better fuel economy in itself may primarily alter the time pattern of oil usage rather than its cumulative total.

In section 3 we discuss the interaction between energy and other policy concerns in the transport sector. Energy policies affect transport problems, like local air pollution and congestion, which are more closely linked with the amount of driving than with the amount of fuel consumed. One implication is that even small increases in the amount of driving, resulting from fuel economy regulations that reduce fuel consumption, may have costly side-effects. Policy measures to control these side-effects are warranted, and some are in place: for example, local air pollution is controlled through per-mile emission limits. But apart from a few well-known cordon pricing schemes (Singapore, London, Stockholm) and some value pricing experiments (Southern California, Texas, Minnesota), congestion is largely uncontrolled.

In thinking about transport policy more broadly, one needs a yardstick by which to compare the importance of the various goals being addressed. We focus on one such yardstick: the marginal external costs of motor vehicle use from various sources. Using this, we find that more prosaic problems such as congestion, air pollution, and motor vehicle accidents demand a higher priority than energy problems as we search for ways to improve transport. We also suggest that transport is probably a sector of the economy that should contribute less than proportionally to reductions in energy use, as other sectors offer cheaper opportunities for fuel switching and conservation. These findings do not negate the significance of energy policy in transport, but they do offer a caution that energy must not become the only, or even the primary, consideration.

2. THE DETERMINANTS OF ROAD PASSENGER TRANSPORT DEMAND AND DERIVED ENERGY DEMAND IN THE LONG RUN

In this section, we review the main determinants of demand for passenger transport using motor vehicles, with a focus on energy consumption. We pay special attention to the US (section 2.1), which is the world's largest consumer of energy for transport purposes and for which abundant data are available. In section 2.2, we briefly consider trends in other countries, and in section 2.3 we look at projections and policies for the next few decades. In section 2.4, we consider evidence on the price sensitivity of transport demand for energy, including its size, manner of variation, and the decomposition of this price response into changes in the amount and the energy intensity of travel. Lastly, section 2.5 summarizes the insights obtained.

2.1 Trends in the US, 1970-2005

We first discuss trends in energy use and then look at its components (vehicle stock, fuel intensity, and mileage). The Transportation Energy Data Book (Davis and Diegel, 2007) conveniently collects the relevant data.

Transport relies on petroleum, and usage keeps increasing

Petroleum consumption by all sectors in the US increased from 17.3 million barrels per day (mb/day) in 1973 to 20.8 mb/day in 2005.[2] That growth was not uninterrupted: consumption hit a low of 15.2 mb/day in 1983. Petroleum consumption from transport, however, grew steadily, from 9.05 mb/day in 1973 to 13.9 mb/day in 2005; consumption fell in all other sectors (residential, commercial, and electricity) except the industrial sector, where it grew slightly. As a consequence, the share of transport in total *petroleum* consumption grew strongly, from 52% in 1975 to 67% in 2005. The share of transport in total US *energy* consumption also grew, from 24.6% in 1973 to 28.2% in 2005. Transport relies almost exclusively on petroleum for its energy, with a 96% share in 1973 and in 2005. The petroleum shares are much lower, and declining, in other sectors.[3]

These numbers illustrate that transport has not substituted out of petroleum, in contrast to other sectors. Combined with the fact that petroleum is relatively highly taxed in transport, this suggests that technological substitution to other sources of energy is particularly difficult in transport. An alternative response to high oil prices is to improve fuel economy. Such responses have taken place, in part because for some transport modes, the market mechanism has been complemented by regulatory interventions, most notably the corporate average fuel economy (CAFE) regulations on new passenger vehicles. But these responses have not been sufficient to offset the strong growth in transport activity.

Light-duty vehicle energy use dominates transport energy use

Next, we consider the breakdown of transport energy use by mode, expressed in trillions of British Thermal Units (btu); see Table 1. While total energy use in transport increased by 78% between 1970 and 2005, that increase was much more pronounced for highway modes (88%) than elsewhere (45%). The greatest growth was for light trucks, partly induced by the CAFE regulations;[4] but growth was substantial in the overall light vehicle fleet as well. Energy use by heavy trucks and aviation grew rapidly as well. Cars and light trucks together accounted for just under two-thirds of all transport energy use, in 1970 as well as in 2005. The shares accounted for by heavy trucks and aviation rose, while those of most other modes declined.

Energy intensity has declined strongly for most modes

Table 2 shows how energy intensity has evolved in transport, leading to several observations. First, all modes except water-borne freight are considerably more fuel efficient in 2005 than in 1970. Second, the strongest reduction in energy intensity occurred for commercial air transport, probably because of increasing aircraft size, higher occupancy rates, and improved technology. (General aviation did not share in this reduction.) On a per passenger-mile basis, commercial air travel is now as efficient as driving a car, but of course air travel tends to be over longer distances. Third, light trucks consume 1.4 times as much energy per passenger-mile as cars, even under the optimistic assumption that occupancy rates for trucks are as high as those for cars. Fourth, fuel efficiency improvements are no stronger for regulated light-duty vehicles than for unregulated modes. This suggests that, if there is a basis for targeting light-duty vehicles for fuel-economy regulation, it is that households make “worse” decisions on fuel economy than do commercial transport operators like trucking firms or air carriers.[5] Finally, buses are now less efficient per passenger-mile than cars, because of declining occupancy rates.

The number of light-duty vehicles and their usage increased on a per capita basis

In 1970 there were 0.48 vehicles per capita, against 0.80 in 2005; for the same years, average annual per capita vehicle use increased from 5,440 to 10,087 miles. Business fleet vehicles are used even more intensively, at approximately 25,000 miles per year. The net impact is that total highway travel in the US grew at a 3.2% annual rate for 1970–1995, and a somewhat lower 2.1% rate for 1995–2005.[6] However, recent traffic data suggest that extended high gasoline prices can eventually interrupt such trends: travel on all roads and streets apparently *declined* by 0.4% between April 2006 and April 2007.[7] Thus high fuel prices can sometimes reduce travel by enough to outweigh the positive (and possibly declining) effect of rising income.

The average trip length in the US has crept upward from 8.7 miles in 1983 to 10.0 miles in 2001 (Pisarski 2006, Fig. 3-7). The average length of a work trip has risen considerably faster, from 8.5 miles to 12.1 miles during the same time period. Much of the growth in commuting trip length is driven by a dramatic rise in suburb-to-suburb commuting trips and a less dramatic but still important rise in commuting trips from suburbs to central cities (Pisarski 2006, Fig. 3-9). It is noteworthy that only 22% of all trips are commuting trips (NHTS 2001). Trips for shopping and for personal business now represent 46% of all trips; however, some of this travel is probably as hard to avoid as commuting travel and harder to shift to other modes.

Summary

Improvements in energy efficiency are not strong enough to compensate for the rise in energy demand caused by increased travel, so that transport energy use continues to increase. There are, however, recent indications that sufficiently high energy prices can slow the growth in travel sufficiently to curtail energy use.

Table 1. **Transport energy use (measured in btu): modal composition and change, USA, 1970 and 2005**

	Highway						Non Hwy					
	Car	Light Truck	Motor-cycle	Bus	Heavy Truck	All Hwy	Air	Water	Pipe-line	Rail	All Non Hwy	All
	% overall energy use											
1970	55.06	9.99	0.05	0.84	10.09	76.02	8.49	5.45	6.43	3.60	23.98	100.00
1990	40.22	20.61	0.11	0.77	15.44	77.15	9.62	6.69	4.27	2.27	22.85	100.00
2005	33.38	29.61	0.10	0.70	16.71	80.49	9.05	4.99	3.07	2.40	19.51	100.00
	Change in energy use by mode, 1970 = 100											
1990	102.5	289.2	342.9	129.5	214.7	142.3	158.9	172.0	93.2	88.5	133.7	140.27
2005	107.8	526.8	385.7	148.1	294.7	188.3	189.5	162.6	85.1	118.4	144.7	177.84

Source: derived from Davis and Diegel, 2007, Tables 2.7 and 2.8.

Table 2**. Energy intensity by mode (btu per "output mile"), USA, 1970-2005**

	Passenger modes										Freight					
	car		LT		Transit bus		Cert. air carrier		Rail transit		HT		Rail		Water	
	btu/pm	ind.	btu/pm	ind.	btu/pm	ind.	btu/pm	ind.	btu/pm	ind.	btu/vm	ind.	btu/tm	ind.	btu/tm	ind.
1970	4868	100	6709	100	2472	100	10282	100	2157	100	24960	100	691	100	545	100
1975	4733	97	6252	93	2814	114	7826	76	2625	122	24631	99	687	99.4	549	101
1980	4279	88	5527	82	2813	114	5561	54	2312	107	24757	99	597	86.4	358	66
1985	4110	84	5008	75	3423	138	5053	49	2809	130	23343	94	497	71.9	446	82
1990	3856	79	4842	72	3794	153	4875	47	3024	140	22795	91	420	60.8	387	71
1995	3689	76	4505	67	4310	174	4349	42	3340	155	22096	89	372	53.8	374	69
2000	3611	74	4545	68	4515	183	3952	38	2729	127	23448	94	352	50.9	473	87
2005	3445	71	4874	73	na	na	3264	32	2784	129	20539	82	337	48.8	514	94

Legend: pm is passenger-mile, vm is vehicle-mile, tm is ton-mile
Source: Davis and Diegel, 2007, Tables 2.13, 2.14, 2.16
Note: Davis and Diegel, 2007, do not provide btu/pm for light trucks - we converted btu/vm using car occupancy rates (which are likely higher)

2.2 Trends in other IEA countries

Oil consumption for transport in all countries belonging to the International Energy Agency (IEA) grew from roughly 600 million tons of oil equivalent (Mtoe) to 1,000 Mtoe between 1970 and 2000. Growth in transport was steady, despite a drop in overall oil consumption in the late 1970s and early 1980s (IEA 2001). Transport relies nearly entirely on oil as its source of energy (approximately 97% in OECD countries: IEA 2002).

Within surface transport, the pattern of energy consumption by mode tends to lie between two extremes: US and Japan. The US has the highest share accounted for by cars and light trucks (66% in 1995), whereas Japan has the lowest (52%). The situation is reversed for truck freight (29% share in the US, 38% in Japan) and for passenger transport by bus and rail (just 1% in the US, 7% in Japan). Thus while the US stands out in its dominance of light-duty passenger vehicles, such vehicles account for the majority of energy consumption for land transport in all IEA countries.

According to IEA (2001), new car fuel economy in the US was roughly on the same level as in Japan and Australia over the period 1980–2000. (It was considerably higher in Europe.) However, the fuel economy of *light trucks*, used mostly for passenger transport and especially prevalent in the US, is much lower than that of cars. Overall fuel efficiency of passenger-vehicle fleets rose modestly from 1980 to 2000 in most IEA nations; but in the US such improvements came to a complete standstill in the late 1990’s, mainly because of the explosion of light truck use. Another way to look at this is that fuel use per unit weight has declined strongly everywhere, but vehicle weight has increased, especially in the US.

Regarding travel demand, IEA (2002) shows that in several European countries (France, UK, the Netherlands), vehicle-km per capita increased from roughly 3,000 to 6,000 between 1970 and 1997. This growth rate is greater than that in the US; however, since the *level* in these European countries is still less than half that in the US, it does not seem likely that Europe will converge anytime soon to US levels of per capita driving.

To summarize, patterns and trends in the US and other IEA countries are not fundamentally different. However, the levels are quite different: the US exhibits persistently higher rates of vehicle ownership and usage and lower fuel efficiency, the latter due in part to the higher prevalence of light trucks in US passenger fleets.

2.3 Future developments

OECD countries now represent 70% of worldwide transport energy use; but according to IEA projections this will decline to 55% in 2030 and to 45% in 2050. The growing share of transport in oil demand is not limited to IEA or OECD Countries, and it is likely to continue. Transport in 1997 already represented 54% of oil consumption in the OECD and 33% in the rest of the world; these shares are projected to increase to 62% and 42%, respectively, by 2030 (IEA, 2006). Fulton and Eads (2004) remark that the growing share of transport in total oil demand leads to a decline in the overall price sensitivity of oil demand, because transport demand is less price-elastic than demand for other energy services. This decline may lead to larger price volatility in response to supply shocks, which in turn is one of the factors driving the recent surge of popular interest in energy policy.

The growth in energy use can be decomposed into changes in transport demand and in the energy intensity of vehicles in use. Eads (2006) projects that globally, light-duty vehicle usage will grow by 1.9% per year for 2000–2050, while energy intensity declines by 0.4% per year; the net result is that total energy demand for passenger transport will grow by 1.5% per year. For air transport, energy use grows by 2.6% per year, deriving from annual demand growth of 3.3% and fuel economy improvements of 0.7%. For trucks, energy use grows by 1.9% per year, with demand increasing at a rate of 2.6% and efficiency improving by 0.7% per year. Projected growth is faster in developing countries, but vehicle ownership there is not expected to reach US levels by 2050, nor will per-capita transport demand reach OECD levels. The main driver for transport demand growth is per capita income. (The IEA assumptions about income growth imply roughly that by 2050, the former Soviet Union, Eastern Europe, and China will reach OECD income levels of 2000, whereas India will by 2050 reach the same level attained by China in 2025.)

Energy consumption in transport is a policy concern in many nations with large markets for motor vehicles. The US, Europe, and Japan use various combinations of fuel taxes, vehicle taxes, and energy efficiency regulation of new cars, but the emphasis varies. Fuel economy is regulated in many parts of the world, but it was introduced in the EU and in Japan only recently, and there is no regulation in India and Mexico, where transport demand is likely to grow strongly in the near future (Plotkin, 2004). In addition, there are large differences in the stringency of fuel economy regulation, differences that are likely to continue (An *et al.*, 2007). The EU and Japan have the most ambitious targets. The US has laxer standards than most other countries, but the current policy impetus seems to be towards stricter regulation. China plans to converge to the strictest standards, but will need time to do so. Regulations are in place in Brazil and South-Korea, but they are not very ambitious.

An *et al.* (2007), reviewing policy developments, suggest that there is increasingly widespread reliance on fuel efficiency regulations. A main reason is that further increases in fuel prices are politically difficult – in rich countries because they are mostly high already, and in poor countries because of concerns about equity (and, we would add, because of political stability). Thus, it is reasonable to expect further regulation-induced declines in the fuel intensity of motor vehicles in many parts of the world.

While increased fuel-efficiency regulations may generate benefits, their value in mitigating climate change is reduced by the fact that they affect the timing, rather than the cumulative amount, of emissions from fossil fuels. The advantages from lowering greenhouse-gas emissions today will to some extent be at risk in the future as the unused stock of fossil fuels remains attractive economically in the absence of measures to raise its price. Strong investments in the efficiency of conventional, carbon-intensive transport technology will if anything tend to *reduce* the price of fossil fuels – indeed, when the discussion turns to energy security that is one of its explicit purposes. Many analysts seem not to have recognized that in this sense, the goals of less climate change and less petroleum dependence are at odds with each other. Thus if fuel-efficiency regulations are used in lieu of price increases, it is important to also use complementary policies to prevent prices from falling and/or to promote technological innovation in alternative energy sources.

Of course, the effectiveness of such complementary policies is subject to limitations. One is that that before investors will embark on major projects to find alternative ways of producing energy, they need assurance that the motivating policies will remain in place for a long time. Another is that high fuel prices for consumers create incentives for manufacturers only to the extent that consumers respond to the fuel costs of travel. This latter concern is the subject of the next subsection, where recent research is shown to suggest that this responsiveness is small and likely declining.

2.4 The price elasticity of fuel demand

This section discusses our own recent work on estimations of the price elasticity of demand for gasoline. There is already a lot of research on this elasticity, but we think ours is particularly informative for the topic at hand, for several reasons. First, we measure not only the price elasticity but two distinct responses that underlie it: changes in amount of driving and changes in fuel intensity. Second, the first of these distinct responses also tells us the magnitude of the "rebound effect," which is one potentially important by-product of fuel efficiency regulations. Third, we investigate how these underlying responses to fuel prices depend on factors like income, the degree of urbanization, and fuel costs. We find that the responsiveness of driving to fuel costs declines with income and urbanization, and increases with the initial level of fuel costs. Considering the magnitudes of these dependencies, by far the most likely outcome for the future is that this responsiveness will decline further, a prediction that substantially affects how transport policies should be designed.

Our work uses a 39-year cross-sectional time series of US states (plus District of Columbia) covering years 1966-2004. This is a three-year extension of the data set used in Small and Van Dender (2007a); otherwise, the methodology reported here is very similar to that paper.[8]

We decompose changes in fuel consumption into three parts: changes in travel per adult (*M*) for a given vehicle stock, changes in vehicle stock per adult (*V*), and changes in the average fuel intensity of vehicles (*Fint*). These changes are specified as three simultaneous equations, estimated simultaneously in logarithms.[9] In this way we overcome one of the confusing aspects of the past literature, which only rarely has accounted for the fact that fuel efficiency (the inverse of *Fint*) is chosen jointly with travel and vehicle stock. (We envision although do not formally model a decision process in which consumers and motor-vehicle manufacturers interact in new-vehicle markets while responding to constraints or incentives set by regulation.) We can then measure the "structural elasticity" of travel with respect to fuel cost per mile, $\varepsilon_{\hat{M},PM}$, accounting for responses both through fleet expansion and through utilization of a given size fleet.[10] Empirically, we find that ignoring the simultaneous determination of travel and fuel intensity would seriously overestimate the magnitude of that elasticity.

Travel (*M*) is generally assumed by us and others to respond to fuel cost per mile P_M rather than responding separately to its separate components (fuel price and fuel intensity). For this reason, the elasticity $\varepsilon_{\hat{M},PM}$ provides information about two different policies. It is part of the price elasticity of gasoline (since gasoline price is one component of P_M); at the same time it measures the responsiveness of travel to changes in fuel efficiency (the other component of P_M). In the latter context, the responsiveness is often called the "rebound effect," so called because it offsets a portion of the fuel savings that would result from an increase in fuel efficiency in the absence of any behavioural response.[11] Following convention, we define the positive quantity $b \equiv -\varepsilon_{\hat{M},PM}$ as the rebound effect, and express it as a percentage. For example, if $\varepsilon_{\hat{M},PM}$ =-0.20, the rebound effect is said to be 20%.

Our empirical system also accounts for the slowness with which changes can occur, *e.g.* because changes in the vehicle fleet require purchases and retirements of vehicles. In this way we distinguish between short and long run responses. Technically, this is achieved by including lagged values of the dependent variables. [12] In the travel equation, this is equivalent to assuming that there is a desired level of travel and that any difference between this desired level and the level attained in the previous year is diminished in one year by a fraction ($1-\alpha^m$), where α^m is the coefficient of the lagged value of the variable. Thus the short-run response (that occurring in the same year) is smaller than the long-run response. The long-run rebound effect is approximately: [13]

$$b^L \cong \frac{b^S}{1-\alpha^m} = \frac{-\varepsilon_{\hat{M},PM}}{1-\alpha^m} .$$

As indicated, our main innovation over previous studies is to specify the equation determining vehicle travel so that the “rebound effect” is not a constant, but rather varies with income, fuel price, and urbanization. This is accomplished by specifying the equation for *vma* (the logarithm of vehicle-miles travelled per adult) so that the logarithm of fuel cost per mile, *pm*, appears not only as a single variable (with coefficient β_{pm}), but also interacted with other variables including itself. We define three such variables: $pm*inc$, $pm*pm \equiv pm^2$, and $pm*Urban$; we call their coefficients β_1, β_2, and β_3. Then the structural elasticity in this equation, which is approximately the negative of the rebound effect, consists of four terms:[14]

$$\varepsilon_{M,PM} = \frac{\partial(vma)}{\partial(pm)} = \beta_{pm} + \beta_1 \cdot inc + 2\beta_2 \cdot pm + \beta_3 \cdot Urban \ . \quad (1)$$

The results of estimating the model are quite similar to what we found for the slightly shorter time period used in Small and Van Dender (2007a). The most important coefficients are summarized in Table 3.

Table 3. **Selected estimation results for the three-equation model, 1966-2004**

Equation and variable	Coefficient symbol	Coefficient estimate	Standard error
Equation for *vma*:			
pm	$_{pm}$	-0.0407	0.0042
*pm*inc*	$_{1}$	0.0696	0.0132
*pm*pm*	$_{2}$	-0.0169	0.0064
*pm*Urban*	$_{3}$	0.0255	0.0100
inc		0.1044	0.0134
Lagged *vma*	^{m}	0.7980	0.0120
Equation for *fint*:			
pf+vma		-0.0297	0.0064
cafe		-0.0882	0.0110
Lagged *fint*	^{f}	0.8450	0.0127

Notes to Table 3:
vma = logarithm of vehicle-miles travelled per adult
pm = logarithm of fuel cost per mile (normalized)
inc = logarithm of income per capita
Urban = fraction of population living in urban areas
fint = logarithm of fuel intensity, i.e. log (1/*E*) where *E* = fuel efficiency
pf = logarithm of fuel price
cafe = variable reflecting how far the CAFE standard is above the desired fuel efficiency based on other variables (Small and Van Dender 2007a, section 3.3.3)
pf+vma is log (price of fuel * vehicle-miles travelled), representing the logarithm of the incremental annual fuel cost of a unit change in fuel intensity; thus it may be interpreted as the logarithm of the "price" to the user, in terms of extra annual operating cost, of vehicle features that cause higher fuel intensity.

For measuring the "rebound effect," our primary interest is in the first four coefficients shown in Table 3. The short-run rebound effect for average conditions in this sample is approximately $-\beta_{pm}=0.0407$, i.e. 4.07%, while the long-run rebound is 4.95 times this value, or 20.1%. The coefficients for the three interacted variables involving *pm* (i.e. β_1, β_2, and β_3) show that the magnitude of the rebound effect declines with increasing income and urbanization, and increases with increasing fuel cost of driving. The net result is that the rebound effect declined substantially over time – which we confirmed by estimating the equation (without the three interaction terms) separately for time periods 1966-1989 and 1990-2004, with the result that the rebound effect fell by half from the earlier time period to the later one.[15]

The coefficient of *inc* confirms the conventional expectation that vehicle-miles travelled rises with rising income: the income-elasticity is approximately 0.1 in the short run and 0.5 in the long run. The coefficient α^m of lagged *vma* shows that the long-run effect of any variable on vehicle miles travelled (VMT) is about $1/(1-\alpha^m)=4.95$ times larger than the corresponding short-run effect. This may seem surprising given our finding that changes in the size of the fleet play only a small role. However, changes in travel can occur either quickly, for example through carpooling or trip chaining, or over a longer period, for example through changes in home and workplace locations or even in land-use patterns.

Our equation system also measures the extent to which the fleet-average fuel efficiency is adjusted in response to fuel prices. The short-run elasticity is approximately the coefficient of *pf+vma* in Table 3, or -0.03, implying a long-run elasticity of -0.15.[16]

We show in Table 4 various implied elasticities, computed at two different sets of values for the explanatory variables *inc*, *pm*, and *Urban*. One set is the average values over our sample and the other is the average values over the last five years of the sample.[17]

Table 4. **Estimated Elasticities**

	1966-2004		2000-2004	
Average values (real 2006 $):				
Household income ($/year)	26,506		33,669	
Fuel price ($/gal)	1.91		1.69	
Calculated elasticities:	Short run	Long run	Short run	Long run
Vehicle-miles traveled	-0.041	-0.210	-0.011	-0.057
Fuel intensity	-0.035	-0.193	-0.031	-0.191
Fuel consumption	-0.074	-0.363	-0.041	-0.237
Rebound effect (%)	4.1%	21.0%	1.1%	5.7%

Source: Small and Van Dender (2007c), estimating using full data set.

Elasticities are with respect to fuel cost per mile for Vehicle-miles traveled, and fuel price for other quantities.

Columns labeled "1966-2004" use average income and fuel cost for the entire sample period.

Columns labeled "2000-2004" use average income and fuel cost for the last five years of the sample period.

Standard errors are approximately as follows:

(a) 1966-2004, short run: 0.004 for "Vehicle-miles traveled", 0.020 for "Fuel efficiency" and "Fuel consumption".

(b) 2000-2004, short run: 0.007 for "Vehicle-miles traveled", 0.020 for "Fuel efficiency" and "Fuel consumption".

(c) Long run: 5-6 times as large as for short run.

Under average conditions over our entire sample period, the measured rebound effect is 4.1% short run and 21.0% long run. However, these values are found to fall dramatically when we consider conditions that prevailed in 2000-2004: over those years the rebound effect on average is just 1.1% short run and 5.7% long run.

Why should rising income diminish the rebound effect? Our model provides no direct answer, but there are some plausible explanations. First, higher incomes cause the share of fuel expenditures in total expenditures to decline, which may lead to lower elasticities. Second, higher incomes lead to higher values of time, so that time costs of travel become relatively more important than fuel costs. Higher fuel costs then translate into proportionally smaller increases in the generalized price of travel (which is the sum of time and money costs), and assuming that drivers respond mainly to this generalized price, this reduces the elasticity with respect to the money costs. However, there are reasons why higher incomes could lead instead to larger elasticities: the share of discretionary driving is likely higher for higher income households, and it is easier to cut back on such driving than on “mandatory” travel. Hughes *et al.* (2006) find larger price elasticities of gasoline demand for higher incomes than for lower income households, while at the same time finding that this elasticity declines over time.[18]

The elasticity of fuel intensity, unlike that of travel, is found to be almost constant, even though we tried specifications that would allow it to vary. This elasticity is somewhat under-researched, with results varying widely depending largely on type of data set. Our results for its absolute magnitude, namely short-run and long-run values of 0.031 and 0.191 over the recent period, are quite similar to the estimates of 0.017 and 0.150 obtained by Li, Timmins and von Haefen (2006), who more directly measure the responses of consumers in the form of model-specific decisions about scrappage and new-vehicle purchases.

The long-run price elasticity of gasoline in our estimates is -0.363 over the entire sample, declining modestly in magnitude to -0.237 over the last five years. With the travel component declining sharply and the fuel-intensity component approximately constant, travel is becoming a notably smaller component of the response to fuel prices. The finding that responses to fuel prices take place through changes in fuel economy more than through changes in the amount of driving is confirmed by a study for twelve OECD countries by Johansson and Schipper (1997), and more recently in a meta-analysis (an econometric analysis of earlier estimates of the fuel price elasticity of the demand for fuel) by Brons *et al.* (2007).[19]

What about the future? In a nutshell, our results suggest that fuel consumption by passenger vehicles has become more price-inelastic over time, and that it is increasingly dominated by changes in fuel efficiency rather than in amount of driving. Furthermore, our results identify two main reasons for this: rising incomes and falling real fuel prices. One of these – rising incomes – can be presumed to characterize the future as well, whereas the other – falling real fuel prices – probably cannot. So we need to consider the relative magnitudes of these two factors.

Real income in the US grew at 1.4% per year over the period 1984–2004 (US Bureau of Labor Statistics 2007). As for gasoline prices, the US Energy Information Agency (EIA) projects in its “reference case” that they will be roughly constant in real terms after declining slightly from a spike in 2005-2006.[20] The EIA also considers low- and high-price cases; in the latter, real prices rise on average by 1.4% per year. In the high-price scenario, then, rising incomes are causing the rebound effect to diminish by 0.097 percentage points per year, while rising fuel prices are causing it to rise by 0.047 percentage points per year.[21] Thus even in a scenario projecting high growth of fuel prices, the influence of income growth dominates; it would do so even more if we used the 2.3%/year income growth projections from US EIA (2007) over the period 2005-2030. Thus we should expect the rebound effect and the price-elasticity of fuel consumption both to continue to become smaller.[22]

2.5 Summary

The demand for oil as a source of energy is likely to grow along with income, especially outside the OECD. With an upward sloping supply curve, this results in higher prices. In addition, the share of the transport sector in total oil demand will likely increase: this reduces the overall elasticity of oil demand, given that transport has very limited access to alternative technologies in the short term. Moreover, the elasticity of fuel demand in transport declines as incomes increase, a pattern which we identified for the US and which we expect applies elsewhere also. This further reduces the price elasticity of oil demand. The declining elasticity implies that short-run supply shocks have bigger price effects and that long-run demand will not be curbed strongly as prices rise.

A common policy response to (real or perceived) excessive costs of reliance on oil is to mandate fuel-economy improvements in the transport sector. Such policies may well be justified, especially when households are thought to under-invest in fuel economy, and when higher fuel taxes are difficult to implement. It is not straightforward, however, that regulation of fuel economy in itself contributes to the mitigation of climate change. The reason is that better fuel economy alters the rate of emissions, but not necessarily their time-aggregated total. This suggests that, if strong reductions in CO2 emissions are desired, fuel economy regulation needs to be complemented by other policies such as a carbon tax.[23]

We have in this section focussed on the connection between energy and transport. In the next section, we put the discussion in the broader framework of transport policy.

3. ENERGY POLICY IN TRANSPORT

We now turn to factors that shape the relative advantages of various transport policies toward energy and other goals. We attempt to create a uniform framework by considering the marginal external costs of fuel-related and other transport externalities.

Long before energy issues rose to their present degree of prominence, transport was an important and often problematic sector in the economies of nations and cities. The many problems identified with the transport sector include large and irreversible investments, financial mechanisms, subsidies, implications for regional economic growth and inter-regional integration, congestion, safety, and negative spillovers to non-users through air pollution, noise, aesthetics, wildlife disruption, water quality, availability of open space, and other mechanisms. These problems have elicited numerous policy responses, some of which increase and some of which lessen the amount of transport undertaken. Furthermore, these policies are often thought to have far-reaching implications for local, regional, and national economies, and they certainly involve strong impacts on government budgets.

One must consider, then, the interaction of energy objectives with the objectives of these other policies. Will attention to energy make other goals easier or harder to achieve? Do these other goals alter in significant ways the optimal response to energy problems? Even aside from other goals, how much of a role should transport policy play in achieving energy objectives? And just how big is energy when viewed as a part of the overall policy environment for the transport sector?

One way to tackle these issues is by asking what responses would markets bring about in an ideal world where prices could be brought into perfect alignment with marginal social costs – i.e. with the extra costs incurred by all members of society, including the decision maker, due to particular economic decisions.[24] This involves looking at each as a market failure, and asking what would happen if that failure could be eliminated within the market system. For example, if we knew the costs global climate change, of macroeconomic disruptions due to reliance on unstable or monopolistic energy suppliers, and of consumers' myopia or lack of information enabling them to optimally trade off energy efficiency against purchase price, and if we could trace these costs to specific economic decisions, then we would know how much prices would have to change in order to confront each decision-maker with the marginal social costs of those consumption decisions. We could then ask how decision-makers would react to such changes in price signals. How much would they curtail transport energy use, and through what mechanisms? Such an analysis provides a guide as to what changes would be the most efficient ones to target, using public policy, if in fact it is not feasible to bring about the theoretically desirable price signals.

The same type of analysis can be done for other transport problems, and has in fact been done in considerable detail for two of the most important – congestion and air pollution – and in a more sketchy fashion for others including noise and safety. Once again, this produces a set of hypothetical responses that thereby become appropriate candidate targets for public policy.

By comparing the resulting behavioural responses across the problems targeted, we obtain answers to the questions asked above. In some cases, behavioural responses to remedy one problem would exacerbate another; in other cases, the responses may work together, "killing two birds with one stone". Furthermore, by considering the relative magnitudes of the price signals involved, one can quantify the judgment involved in the last question posed: how big are these problems relative to each other?

A comprehensive analysis of this type would consume a work the size of an encyclopaedia. We provide here a first cut, by considering two questions. First, what are the relative sizes of the marginal external costs of various transport problems, when averaged over a large class of users? (Marginal external cost means that part of the marginal social cost not incurred by the decision maker.) Second, how dramatically do those costs vary across user groups or local situations? And if they do vary, do the responses that would be undertaken in response to internalizing those costs also vary? If so, then there is a strong case for looking at closely targeted policies that can bring about such diverse responses; if not, then a blunt instrument that changes average behaviour may be adequate. Local air pollution, and to a stronger extent congestion, are examples of externalities where blunt approaches are not usually considered to be effective because what is needed is a set of changes in very specific situations like driving in big cities during peak periods, or driving a vehicle whose emission control mechanisms are not working.

Table 5 collects estimates of marginal external cost due to several types of transport problems. They are classified according to whether they vary mainly in proportion to fuel consumption, which is the case for climate change and oil dependency, or in proportion to vehicle-miles travelled. For comparison, the former are converted to a marginal cost per vehicle-mile, using the fleet average fuel efficiency for passenger vehicles (*e.g.* 22.9 mi/gal for the US in 2005). Note however that in terms of the thought experiment described above, the best policy responses to fuel-related and mileage-related externalities are quite different. Raising the price of fuel induces not only a mileage reduction but a substantial increase in fuel efficiency, the latter increasingly dominating as described in the previous section. As emphasized by Ian Parry and Small (2005), this difference dramatically affects the (second-best) optimal use of a fuel tax to address mileage-related externalities: using their numbers, the tax rate would be set at only roughly 40 percent of the value that would be calculated by multiplying the cost/mile figures by fuel efficiency. Conversely, using a distance-related tax (sometimes called a VMT tax) to address a fuel-related externality such as global warming would fail to elicit one of the most important responses needed, which is an increase in fuel efficiency of vehicles.

Table 5. Marginal external costs from automobiles, US cents/mile, 2005 prices

	Harrington-McConnell (US & Europe)		**Sansom *et al.* (UK)**		**Parry *et al.* (US)**	**High fuel-related[a] (US)**
	Low	**High**	**Low**	**High**		
Fuel-related: [a]						
Climate change	0.3	1.2	0.5	2.0	0.3	3.7
Oil dependency	1.6	2.7	n.a.	n.a.	0.6	2.4
Driving-related:						
Congestion	4.2	15.8	31.0	35.7	5.0	5.0
Air pollution	1.1	14.8	1.1	5.4	2.0	2.0
Noise, Water	0.2	9.5	0.1	2.5	n.a.	n.a.
Accidents	1.1	10.5	2.6	4.5	3.0	3.0
Total	6.6	50.6	35.3	50.1	10.9	16.1
Percent fuel-related	22	7	1	4	8	38

Sources: Harrington and McConnell (2003), Table 3; Sansom *et al.* (2001); Ian Parry, Walls and **Harrington (2007), Table 2. "High Fuel-related".: same as Parry *et al.* except for climate** change ($0.76/gal, from Stern 2005) and oil dependency ($0.55/gal, from the high end of range in Lieby (2007), Table 1.

Notes: All numbers converted to 2005 US price levels. n.a. means not estimated, in some cases due to an explicit argument that the quantity is small. Fuel-related costs are converted from per gallon to per mile using prevailing average fuel efficiency.

The fuel-related costs portrayed in Table 5 are potentially very large in aggregate. Taking the "high" values of the last column, and multiplying by just the 2.99 trillion vehicle-miles travelled in the US in 2005, they come to $111 billion for global warming and $72 billion for oil dependency annually.

Yet it appears that other, more prosaic, transport problems are even larger. The three studies listed in Table 5 (excluding the last column) are unanimous in finding that congestion involves larger external costs than fuel-related externalities, and except for the "low" Harrington-McConnell values, the same is true of air pollution and accidents. In nearly all cases, congestion alone is found to outweigh the fuel-related externalities by a large margin. These findings may seem surprising until one realizes that congestion and air pollution have tangible and serious effects on most urban residents on a daily basis. Congestion consumes huge amounts of time, and air pollution produces demonstrable mortality. Climate change and oil dependency, by contrast, have effects that, as best as can be determined from the admittedly imperfect modelling available, are in the distant future, capable of substantial amelioration by other means, and/or simply not very large when spread over the enormous number of vehicle-miles producing the estimated aggregate impacts.

What about variation? The figures in Table 5 are national averages, but some of these costs vary strongly over time and place. For example, a recent French study, discussed in Grange (2007), finds that the marginal external congestion costs of driving in urban traffic are about ten times as high as those of driving in interurban traffic. This conclusion is corroborated by other studies, which in addition point out that the congestion costs depend strongly on time of day (e.g. Proost *et al.*, 2002). This is a second reason why fuel taxes are not well suited to deal with congestion. There is strong evidence that the response to imposing targeted congestion charges (i.e. ones that vary by time and place) would involve a lot of shifting of trips across time periods, modes, and routes, and much less overall reduction of trips; thus the most efficient policies would aim at shifting trips in this manner rather than simply reducing all trips.

Similarly, pollution costs from motor vehicle-use vary widely depending on location, fuel type, age of vehicle, and vehicle maintenance practices. for example, pollution costs are higher for diesel than gasoline cars, because of the high health costs associated with emissions of small particulates. This casts some doubt on whether the European “dieselization” strategy to increase fuel economy is opportune, as it increases emissions of particulates unless particulate filters become universal. The US may embark on a “hybridization” strategy, which avoids the particulates issue but which also involves expensive technology. More generally, given the high costs of further improvements of emission abatement technology, one may question the desirability of this policy approach, as policies to reduce emissions from small numbers of gross polluters become more attractive (Small, 1997).

If we use the higher fuel-related figures in the last column of the table, the picture changes somewhat – although even then fuel-related externalities do not dominate other externalities. However, we think these higher figures are not well supported by existing evidence. In order to support this claim, we now consider more carefully the sources of the estimates shown for fuel-related externalities, first for climate change (section 3.1) and then for oil dependency (section 3.2).

3.1 Marginal external costs of motor-fuel consumption due to climate change

The climate-change cost calculated by Parry *et al.* (2007), shown in the next to last column of the table, is based on a damage estimate of US$25 per tonne carbon, i.e. $25/tC, at 2005 prices.[25] This figure is consistent with results from a number of reviews including Cline (1990), Nordhaus (1994), ECMT (1998, p. 70), and Tol *et al.* (2000).[26] More recent reviews include Tol (2005), who reaffirms the validity of relatively low costs,[27] and Stern (2006, pp. 287-288), who argues for much higher costs as discussed below.

Quantifying such costs is of course highly speculative, due especially to three features of climate change. The first is the highly uncertain effect of emissions on specific climate outcomes; it is usually handled by acknowledging the uncertainty and stating results in terms of a specific assumed climate outcome, most often based on reports of the Intergovernmental Panel on Climate Change (IPCC).

The other two features, however, give rise to two sources of major differences among analysts. One is the unknown form of human adaptation to problems building up over decades and centuries. The other is differences of opinion about the appropriate analytical procedure for aggregating effects occurring over long time intervals. We consider each of these sources of controversy in turn.

Human adaptation to climate changes may occur in many ways, including changes in crops (*e.g.* Mendelsohn *et al.*, 1994), public health measures, new water storage facilities, coastline protection measures, and human migrations. Tol (2005) and a working group of the IPCC (Martin Parry *et al.* 2007) provide thorough discussions. Such adaptive measures are expected to greatly reduce the damage that would otherwise occur. To take one example, the European Commission (2007, p. 10) estimates that European damages from a 56 cm rise in sea level in the 2080s would be approximately €18 billion per year without adaptation but €3 billion with adaptive measures. Similarly, the relevant IPCC working group notes that “adaptation costs for vulnerable coasts are much less than the costs of inaction” (Parry *et al.* 2007, p. 40). Some adaptive measures will be extremely costly, but these costs will be spread over many decades. Some, like migrations, may turn out to exact a terrible human toll, just as do natural catastrophes and various failures of governmental policies today. And adaptive measures cannot mitigate all damage: species extinctions, flooding, damage to deteriorating aquatic environments, fresh water shortages, and many other adverse effects are very likely to occur despite adaptation. Of course, such adverse events are already occurring today, primarily for other reasons; so the relevant questions become quantitative ones of how much and at what cost.

Measurement of the ultimate costs is full of hazards, but real progress has been made, especially with respect to converting damages to monetary costs. The evidence so far does not indicate that such costs dominate the more prosaic costs of congestion and air pollution that we have become accustomed to in the field of transport. An analogy with a different transport problem may be useful. The collapse of a well-used bridge in Minneapolis in August 2007 elicited expressions of great urgency for dealing with the problem of US infrastructure deterioration. Yet the resulting 13 deaths are far less than just one day's average fatalities from US motor-vehicle accidents (116 in 2004). So which is the larger national problem: infrastructure deterioration or routine safety? It is this kind of question that is implicitly addressed by cost figures like those in Table 5. To the extent they are valid, the appropriate conclusion is not to ignore the problems with smaller costs; it is rather to maintain perspective relative to other problems, even prosaic ones, when setting priorities.

The second major source of differences among analysts is the matter of "discounting" future costs in order to aggregate them into a number applicable to an emission produced at a specified time (*e.g.* today). This is a technical debate, largely over the ethical meaning and economic interpretation of parameters that characterize modern models of economic growth. In what Weitzman (2007) calls the "majority view" of most economists, distant economic consequences should be discounted at interest rates on the order of 4%–6%. This view relies in large part on the fact that observed savings behaviour appears to be roughly consistent with a long-term growth model in which people discount their own or their descendants' future utility at very modest interest rates (the so-called "pure rate of time preference"), and simultaneously seek to smooth their consumption in a world where long-term growth is making them richer. The consumption smoothing part of this justification can be stated equivalently as an ethical position against income inequality across generations. In this interpretation, since future generations are likely to be richer than us, we would discount the advantage to them resulting from any sacrifice by us. Yet another justification is that the world economy is capable of generating returns on investments of at least 4%–6%, and these returns may be used to mitigate or compensate for the adverse future consequences of climate change.

There is actually little disagreement among economic analysts about the principles just stated. The disagreement comes in the form of numerical parameters. The "majority view" infers from savings behaviour that people apply a pure rate of time preference of 1–3% per year, both for themselves and for descendants to whom they bequeath wealth. Others, however, argue that for purposes of policy any such preferences must be overridden by an ethical principle that future generations are just as important as current ones. Most prominently, the *Stern Review* issued by the UK Treasury (Stern 2006) argues that the only legitimate basis for a pure rate of time preference is uncertainty over whether those future generations will actually be alive, resulting in use of a pure rate of time preference of just 0.1%. As for the aversion to income inequality, Stern uses a parameter that implies indifference between a given *percentage* loss in world output at any point in time; whereas the "majority view" is for a greater aversion to income inequality so that one would not accept a 1% cut in living standards today in order to achieve a 1% increase at some time when people are ten times richer. The implication of Stern's assumptions is an actual discount rate of only 1.4% per year (Weitzman 2007).

Nordhaus (2007) argues that these two parameter assumptions used by Stern, taken together, are inconsistent with people's observed behaviour, in particular implying they would choose to save much more than they do. (See however the rebuttal to this type of argument in Stern, 2006, pp. 47-48.) More transparently, Nordhaus provides some numerical examples of the implications of using Stern's 1.4% social discount rate. Suppose a "wrinkle in the climatic system" threatens to reduce world consumption by 0.1% forever, starting in year 2200. It could be averted by sacrificing 56% of one year's world consumption today. Stern's methodology produces the result that we should undertake that expense; the low interest rate for discounting turns the climate wrinkle, which might never even be noticed, into a catastrophe in present value terms.

It is worth noting that the *Stern Review* itself, despite its language of catastrophe, does not project world per capita consumption to decline in real terms, even with uncontrolled climate change. Rather, in the worst of all the cases calculated, it is projected to grow to 8.6 times today's level by year 2200, instead of to 13.2 times as it would in the absence of climate change.[28] Yet because this reduced income continues forever, and is discounted at only 1.4% per year, it has a present value equivalent to reducing per capita consumption by 14.4% every year from now to forever (Stern 2006, Table 6.1). Thus Stern would evidently recommend that we cut world consumption if necessary by 14%, starting today and lasting forever, in order to prevent our descendants from having to live with a lower income growth than they otherwise would enjoy. Would we really accept such a bargain? These examples illustrate the hazards to common sense that accompany arguments about long time periods with very low discount rates.

Weitzman (2007) provides an insightful discussion of a possible alternative rationale for the parameter values used by Stern. In Weitzman's view, the most important issue is uncertainty about the prospects and consequences of unlikely but extremely damaging results of climate change – events such as collapse of a continental ice sheet or reversal of a major ocean current. Neither Stern nor his critics have a way to model this type of uncertainty rigorously. Weitzman posits that because of this, Stern may have "tweaked" his parameter values intuitively to reflect it. The trouble is that such uncertainty takes us into possibilities that we know little about and cannot model well. Weitzman's own conclusion is that the "majority view" provides a good starting point for immediate policy, but that the uncertainty justifies a crash program of research and policy debate aimed at learning about the potential adaptations to and ultimate consequences of small-probability catastrophes. Weitzman also shows, using several examples, that the response called for may well be closer to that coming out of Stern's model than that from the majority view.

This technical discussion may seem to disconnect from the main thrust of Stern's and many other people's analyses of climate change. These writings are filled with descriptions not of happy people enjoying living standards ten times greater than today's, but rather of terrible disruptions to their well-being. Yet the technical analysis just described is the one that underlies Stern's damage figure of US$96 per tonne CO2 (at 2005 prices), equivalent to $352/tC or $0.85/gal for gasoline.[29] Part of Weitzman's critique is that Stern may have adapted the parameters of a highly technical and, perhaps, ultimately unsatisfactory analysis using conventional growth theory in order to capture the possibilities, even if remote, that the world will turn out much worse than the scenarios being modelled. Unfortunately, there does not at present seem to be an adequate basis for analysis of such contingencies within a decision-theoretic framework.

3.2 Marginal external costs of motor-fuel consumption due to oil dependency

Some sophisticated analysis has gone into measuring a marginal social cost for fuel consumption due to oil dependency. One of the most thorough and recent is Leiby (2007). Ian Parry and Darmstadter (2003) provide a useful review, citing studies producing estimates of from zero to US$0.33/gal; their own preference is $0.125/gal. (See also Davis and Diegel 2007, table 1.8.) Leiby (2007, Table 1) obtains a range by considering likely parameter values within a single model: when divided by 42 gal/bbl, his range is $0.16–$0.55 per gallon, with a preferred value of $0.32. We include the value $0.55/gal in our "High fuel-related" column of Table 5.

However, we have severe reservations about accepting these numbers as indicators of the marginal value of reducing oil imports. The costs of oil dependency are essentially the total cost to a national or regional economy (specifically that of the US) of various features of the world oil market that cause problems to a nation relying heavily on oil imports. Specifically, the features considered by these authors are a "monopsony premium" and the costs of macroeconomic disruptions. The first is rightly described Leiby as a foregone opportunity: because the US is a large part of the world oil market (on the buying side), it could, by exerting coordinated national policy, reduce our import demand as seen by the Organization of the Petroleum Exporting Countries (OPEC) and thereby reduce OPEC's monopoly power. But the lion's share of the monopsony premium consists of curtailing the transfer of wealth abroad to OPEC nations, not a saving of world resources. Indeed, the analysis takes as given that the inefficiency of OPEC's monopoly power is by reducing world consumption below efficient levels; so it is unclear that further reducing world consumption would create worldwide benefits. Rather, it is mainly an attempt to reduce a transfer occurring through the workings of world trade. It seems to us inconsistent to use a worldwide perspective in valuing climate-change costs while adopting a parochial perspective in valuing oil dependency costs.

This leaves costs of macroeconomic disruption. There is evidence that normal price fluctuations in world oil markets are magnified by the distortion of monopoly power, and that resulting fluctuations in oil prices tend to cause macroeconomic instability, in particular recessions following oil-price increases. These recessions carry an economic cost that can be regarded as an external cost to the consumption decisions of individual economic decision-makers. We do not disagree with this analysis, although it must be qualified by recognizing that both of these pathways are subject to institutional factors which may change – in particular, national banks are becoming more "savvy" about counteracting oil-price shocks. But as with OPEC monopoly power, the obvious implication is that market prices are too high, not too low. Thus macroeconomic disruption is not an argument for raising the price facing decision-makers, in the usual manner of an unpriced external cost. Rather, as acknowledged by Leiby, it is an argument for other policies that reduce the extent of price fluctuations or their adverse impacts on macroeconomic performance.

Thus both components of the oil-dependency costs, as measured by current studies, may be seen as indicators of the potential value to the economy of a large nation or region of reducing the proportion of its supply consisting of imports from monopolized and/or unstable sources. It is less clear how exactly reducing transport use of conventional oil fuels brings about this desired result. Curtailing demand, for example by fuel-efficiency standards or incentives to reduce motor-vehicle travel, would come partly from domestic sources (which are currently producing some oil at very high marginal cost due to high world prices). Thus such reductions cannot be taken one for one as reductions in imports, and in fact it's unclear whether they would even change the *fraction* of US consumption represented by imports. Thus while oil dependency may well be a problem that warrants action, the relevant factors are more country-specific and the relevant policies more specific to trade and macroeconomic conditions than the other problems discussed here. Furthermore, simply raising the price is not obviously a solution, since many of the drawbacks of oil dependency result from the price being artificially high.

To summarize, oil dependency is an argument for interventions to reduce the market power of oil producers by promoting conservation or substitutes for oil. It has significance for transport policy, but it does not provide an argument for fuel taxes or for other interventions that would raise the domestic price. On the contrary, oil dependency and climate change have offsetting effects on world oil consumption, the first reducing it and the second increasing it relative to a social optimum. To put it differently, if one takes climate change as the truly overriding policy problem, then one must welcome the possibility that world oil markets are organized in such a way as to keep current oil consumption artificially low.

3.3 Implications of analysis of marginal external costs

We believe that damage estimates of the orders of magnitude shown in Table 5, excluding the right-most column, are the best guides to transport policy within the limitations of quantifiable uncertainty. Several unpriced external costs of motor vehicle travel appear to have larger measurable external costs – when traced specifically to motor vehicle use – than those of climate change and oil dependency.

This finding does not imply that control measures are unwarranted. On the contrary, when totalled over the trillions of vehicle-miles currently being driven throughout the world, these costs are large and warrant significant policy interventions. It is less clear that they are amenable to amelioration through transport policy. Furthermore, even from a broader policy perspective, there are tradeoffs. Reducing greenhouse gases and energy insecurity are important and valuable activities, but so are other uses of our resources. For example, IPPC (2007) notes that the ability of poorer nations to cope with the climate change that is already certain to occur is greatly affected by their development path; so one must weigh greenhouse gas control against development needs in circumstances where they compete for funds or attention.

More specifically for transport, we reach two conclusions. First, one must pay attention to the side effects of control measures on such prosaic but real costs as air pollution, traffic accidents, and above all congestion. The idea that climate change is so overwhelmingly catastrophic that it trumps all other environmental or transport policies – an idea expressed or implied by some recent writings – is wrong and quite dangerous.

Second, an ideal approach to controlling energy use is not likely to reduce motor vehicle travel very much. We know from our study of demand elasticities that users would curtail travel only slightly if faced with its fuel-related external costs. Furthermore, it seems likely that abatement costs are higher in transport than in some other sectors (e.g. Knockaert and Proost, 2005), which suggests that it is more effective to focus abatement efforts elsewhere. An ideal approach will accomplish most of its results through technological changes specifically targeted to energy savings, mostly through the use of more fuel-efficient vehicles and perhaps also through alternative fuels. By choosing technological solutions when permitted, consumers will avoid more thoroughgoing behavioural changes such as changes in travel mode, trip patterns, and home and work location, which evidently are more costly for them.

Combining the marginal-cost analysis with our review of fuel-consumption elasticities, it appears that transport is not the ideal sector to target for solutions to energy problems. It surely can and should play a role, but not the dominant one that some assume. Where, then, might we find a better avenue for energy policy? Many analysts have identified electricity production from fossil fuels as a promising one because it entails more economical opportunities for fuel switching or conservation. To review the electricity sector would take us outside our scope, but we can cite one statistic that helps make the point. Ian Parry (2005) discusses the implications of the “majority view" of the external cost of carbon emissions, taking it to be $30/tC. Applying an externality tax of this magnitude would raise the price of gasoline by $0.07 per gallon, not enough to have much effect on motor-vehicle fuel consumption. But applying such a carbon charge to coal would more than double coal prices![30] This would have significant effects on producer, and maybe even consumer, decisions about electricity production and use. It would of course also affect other industrial uses of coal, which are increasing at a frightening rate in fast-growing economies like that of China.

4. CONCLUSION

Our analysis suggests that transport is relatively unresponsive to broad-based price signals, in particular to changes in prices of fuels. The main exception to this is that there is considerable scope to improve the fuel efficiency of vehicle fleets, mainly through technological changes but also to some extent through consumer choices among vehicle sizes and types. As a result, we should not expect to see dramatic changes in modal shares or in the nature of transport systems. Furthermore, this unresponsiveness suggests that it is costly to reduce energy use in transport, relative to other economic activities, and thus that efficient policies will probably not extract as much energy savings (in percentage terms) from transport as from other sectors.

A perennial policy issue is whether to address problems with price incentives (in this case, higher prices) or with regulatory measures. Our review suggests that either approach can work. Using prices has the disadvantage that quite large price increases are needed to obtain much response, and this may be beyond the political capacity of most countries. Fuel efficiency regulations are a relatively quick way to reduce oil imports where energy security is a concern, and the danger of inducing more travel as a side effect is probably minor. But if reducing climate change is a primary goal, we think it is important to supplement any regulations with either technology policies or some price-oriented policies because otherwise the stock of fossil fuels remains available and attractive for future use, making it that much harder to move toward a global path of lower carbon-dioxide emissions.

Broad-based carbon taxes remain an excellent tool for climate control. Their impacts on transport would be modest, mainly in the form of promoting technological improvements and vehicle-mix shifts that increase fuel efficiency. This is at it should be, because it reflects relatively high costs of reducing oil use in transport. There are other sectors, especially those that burn coal, that make better targets for energy policy.

Our review of marginal external costs suggests that energy policy could be the "tail wagging the dog" in transport. Other transport problems, notably congestion, local air pollution, and accidents, are associated with considerably higher marginal external costs than are climate change and energy security. It follows that policies to deal directly with these other problems deserve high priority, regardless of energy policies.

NOTES

1. Figures taken from CEC (2007, p. 26) and converted to 2005 prices using the US Consumer Price Index (CPI).

2. Crude oil accounted for 90.6% of all petroleum used in 2005 (TEDB, Tables 1.2 and 1.3).

3. See Davis and Diegel (2007), Tables 1.13 and 2.1 for the figures quoted in this paragraph.

4. CAFE regulations were much stricter for cars, which probably induced manufacturers to produce light trucks as substitutes. We suspect furthermore that the prevalence of light trucks in the vehicle fleet became self-reinforcing by inducing changes in consumer preferences, due to a fad effect and/or an “arms race” as each driver seeks to avoid colliding with vehicles much larger than his or her own.

5. Various explanations of why households under-invest in fuel economy have been put forward, for example “consumer myopia” (possibly because private discount rates exceed social ones) and loss aversion (consumers undervalue future fuel savings because they are unsure about them and risk averse). See Greene and German (2007). There also is evidence that consumers do not accurately calculate benefits from fuel economy (e.g. Turrentine and Kurani, 2007), but this does not imply systematic errors in the direction of underinvestment.

6. The source for these figures is Davis and Diegel (2007), Tables 8.2, 7.3, and 3.4.

7. US FHWA (2007). These preliminary data are extrapolated from a fairly small number of traffic counting locations, and are less reliable than the final estimates (derived from the Highway Performance Monitoring System) published for earlier periods.

8. See Small and Van Dender (2007a,b) for further methodological details.

9. The equations are estimated using three-stage least squares. In order to account for fixed factors affecting a given state, we use a “fixed effects” specification which estimates a separate constant term in each equation for each state.

10. This structural elasticity comes from the first two of our equations, explaining travel and vehicle fleet size. Small and Van Dender (2007a) show that it can be written in terms of the elasticities measured within these two equations:

    $$\varepsilon_{\hat{M},PM} = \frac{\varepsilon_{M,PM} + \varepsilon_{M,V}\varepsilon_{V,PM}}{1 - \varepsilon_{M,V}\varepsilon_{V,M}}$$

    where $\varepsilon M,PM$ denotes the elasticity of travel with respect to fuel cost per mile in the travel equation; $\varepsilon M,V$ denotes the elasticity of travel with respect to vehicle fleet in that same equation; and where $\varepsilon V,M$ and $\varepsilon V,PM$ denote the elasticities of vehicle fleet size with respect to amount of travel and to cost per mile, both within the second equation. Cost per mile of travel, *PM,* is defined as the price of fuel times fuel intensity. Thus $\varepsilon_{\hat{M},PM}$ depicts the result of a hypothetical exogenous change in *PM* (or of an endogenous change in *PM* caused by an exogenous change in regulations affecting fuel intensity); yet the actual estimation of these component elasticities accounts for the simultaneous determination of vehicle stock, vehicle usage, and fuel intensity within the estimation sample. Empirically, we find that $\varepsilon M,V$ is very small, so that $\varepsilon_{\hat{M},PM}$ differs little from $\varepsilon_{M,PM}$.

11. A distinction can be made between direct and economy-wide rebound effects. Our estimate concerns the direct effect, as it is limited to the effect of increased fuel economy on travel while holding constant all other factors except vehicle stock. But wider economic effects clearly exist that affect energy consumption: for example, consumers will spend some of their saved energy expenditures on other goods that also consume energy. Empirical evidence on such indirect effects is relatively scarce. According to one review, computable general equilibrium models generate values of the economy-wide rebound effect of around 50%, whereas a UK macro-econometric model generates a value of 7% (Sorrell 2007, p.58).

12. Another dynamic effect we account for is autocorrelation among the error terms in each equation; however, our specification is comprehensive enough that autocorrelation, which is indicative of important omitted variables, is quite small. In previous research, using shorter time periods, it has been difficult to distinguish between autocorrelation and lagged dependent variables, which is important to do in order to distinguish short- and long-run responses.

13. A more precise relationship accounts for the fact that in the three-equation system, the lagged values in more than one equation can affect the long-run response; specifically:

$$b^L = \frac{-\varepsilon_{M,PM}\cdot(1-\alpha^v)-\alpha^{mv}\beta_2^v}{(1-\alpha^m)(1-\alpha^v)-\alpha^{mv}\alpha^{vm}}$$

where αv is the coefficient of the lagged dependent variable in the equation explaining vehicle stock, αmv is the coefficient of vehicle stock in the equation explaining travel, αvm is the coefficient of travel in explaining vehicle stock, and β_2^v is the coefficient of *pm* (the logarithm of cost per mile) in the equation explaining vehicle stock. All the dependent variables are expressed in logarithms. See Small and Van Dender (2007a), equation (7).

14. The factor 2 in this equation is a consequence of properties of the derivative of the quadratic function (*pm*)2.

15. More precisely, the short-run rebound fell from 4.8% to 2.9%, while the long run rebound fell from 21.1% to 7.7%. These declines are not in the same proportion because the estimated coefficient of the lagged dependent variable also changed between time periods.

16. The precise equations for the short-run and long-run elasticities of fuel efficiency with respect to fuel price, again accounting for feedbacks across all three equations, are shown as equation (9) in Small and Van Dender (2007a).

17. The third elasticity shown is the price elasticity of gasoline consumption, calculated as follows: $\varepsilon_{F,PF} = \varepsilon_{\hat{M},PM}\cdot(1+\varepsilon_{\tilde{I},PF})+\varepsilon_{\tilde{I},PF}$, where $\varepsilon_{\hat{M},PM}$ and $\varepsilon_{\tilde{I},PF}$ are the elasticities reported in the previous two rows of the table. This equation is derived by USDOE (1996, p. 5-11) and Small

and Van Dender (2005, eqn. 6); the term $(1+\varepsilon_{\tilde{I},PF})$ was inadvertently omitted in Small and Van Dender (2007a) when calculating elasticities of gasoline consumption, causing those elasticities to be slightly overstated – see Small and Van Dender (2007b) for the correct values for the shorter (1966-2001) data set used in those papers.

18. Yet another factor is that richer households own more vehicles, allowing them to respond to fuel price increases by using the more fuel-efficient vehicles more intensively. This seems mainly a short-run reaction, and would tend to make them respond less through changes in travel but more through changes in average realized fuel efficiency. Basso and Oum (2007) discuss conflicting evidence from cross-sectional studies on the relationship between income and the price elasticity. Most recently, Wadud *et al*. (2007a,b) find, as we do, that the price elasticity is smaller at higher incomes.

19. The meta-analysis does not investigate whether the price-elasticity of fuel consumption depends on income. However it does test whether it depends on a pure time trend, after all other measured determinants are controlled for, finding no evidence of such dependence. This result is consistent with our model, which also finds no significant time trend in the rebound effect, even when the three interaction terms in the estimating equation are removed. We interpret this to indicate that a simple time trend is inadequate to capture the effects of the complex changes in income, urbanization, and fuel cost over the time periods covered by the various studies.

20. See US EIA (2007), "Year-by-Year Reference Case Tables (2004-2030)," Table 3, for average price of motor gasoline. Prices are projected to decline slightly in real (inflation-adjusted) terms, by an average of 0.2% per year, over the period 2005-2030.

21. These numbers are calculated from the figures in Table 3, using equation (1), as 0.0696*0.014*100 and 2*0.0169*0.014*100, respectively.

22. At some point our equations predict that the rebound effect would become zero and then negative; obviously this is contrary to theory and must be regarded as a limitation of extrapolating our equations beyond the primary range of the data set on which they are estimated.

23. If economy-wide rebound effects are large, which is uncertain but possible (cf. footnote 8), this is an additional reason for combining fuel economy regulations with fuel or carbon taxes.

24. This is a simplification, as the presence of market failures and policy concerns outside the transport sector implies that optimal transport prices likely deviate from marginal social costs; in the jargon, we are in "second-best". The exact nature of such deviations is difficult to determine, but recent research suggests that the deviations may be smaller in the transport sector than in other sectors, because price changes in transport do not strongly exacerbate other inefficiencies in the economy, notably those related to labor taxes (West and Williams, 2007). At any rate, it is very likely that second-best transport pricing would align charges more closely with external costs than is the case for the current price structure, so that the comparison discussed in the text is a useful one.

25 One tC means one metric ton or tonne (1000 kg) of carbon. Given that carbon comprises a fraction 12/44=0.27 of the weight of a carbon dioxide molecule, \$1 per tC is equivalent to

$3.67 per metric ton of CO2. According to National Research Council (2002, p. 85), one tC is the carbon content of 413 gallons of gasoline.

26. See, for example, the discussions in Small and Verhoef (2007, ch. 3) and Parry and Small (2005). The damage estimate of $25/tC is also consistent with the "shadow price" of carbon coming out of optimization models of economically efficient paths toward greenhouse gas control, the most well-known being a series of models developed over many years by William Nordhaus, of which a recent version is the regional integrated model of climate and the economy, or RICE model (Nordhaus 1994). Nordhaus (2007b) describes a recent calculation using this model as leading to a carbon price of $17/tC in year 2010 (stated at year 2005 prices) rising to $70/tC in 2050. The "optimal" calibration reported in Nordhaus (2007a) produces a price of $35/tC in 2015, $85/tC in 2050, and $206/tC in 2100. These numbers encompass all the estimates underlying Table 5 except for Stern's. The damage estimate can also be compared to the actual trading prices of carbon permits in the EU's Emissions Trading Scheme. If the market is working smoothly (a highly debated proposition in this case), these prices should reflect the marginal costs to industry of enacting controls to meet the mandates of the EU under the Kyoto Protocol. In actual experience this market has fluctuated substantially, with prices between €6 and €30 per tonne of carbon dioxide during a period covering most of 2004-06 (Convery and Redmond 2007, Fig. 2), which equate to $27–$138/tC (given that the carbon atom constitutes 12/44 of the atomic weights in a molecule of CO2, and using the average 2004-06 exchange rate of 1€=$1.25). These figures suggest that in Europe, at least, the marginal control cost has been pushed to well above the lower estimates of marginal damage cost in Table 5.

27. Tol (2005) reviews 103 estimates of marginal CO2 damage costs, taken from 28 separate studies done by 18 distinct research groups. The median estimate is $14/tC, but the estimates are highly skewed to the right, with unweighted mean $93/tC and standard deviation $203/tC. The mean estimate declines substantially, to $43/tC, when only peer-reviewed studies are included; so does the standard deviation, to $83/tC. There is a clear effect of methodology – especially using a very low interest rate for discounting and using "equity weights" to aggregate across countries – in accounting for most of the higher estimates. Tol concludes: "Using standard assumptions about discounting and aggregation, the marginal damage costs … are unlikely to exceed $50/tC, and [are] probably much smaller" (p. 2064).

28. These numbers are calculated from Stern's assumed 1.3 percent per year growth rate of per capita output in the absence of human-induced climate change, applied for a period of 200 years, and diminished by 35.2 percent according to the 95th-percentile loss in the worst scenario shown, that labelled "High Climate, market impacts + risk of catastrophe + non-market impacts" (described on p. 156 and in Figure 6.5c). Nordhaus (2006, p. 18) makes a somewhat similar calculation in a working-paper version of his 2007 critique.

29. We have restated Stern's figure of $85 (Stern 2006, p. 287) from year 2000 to year 2005 prices, using the 13.4% growth of US Consumer Price Index over that time.

30. The US price of coal in 2003 was $19.68 per metric ton (US EIA 2006, Table 7.8, converted to metric tons) with carbon content 0.75 (O'Hara 1990, Table 6), implying a price of $26/tC.

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OIL DEPENDENCE: IS TRANSPORT RUNNING OUT OF AFFORDABLE FUEL?

Oil consumption is increasingly concentrated in transport and relatively limited fluctuations in transport demand can have increasingly significant effects on oil prices. Oil prices rose to all time highs at the beginning of 2008, exceeding $100 a barrel for the first time since the 1979 oil crisis. The underlying driver was demand for oil from rapidly developing economies and especially China, where transport accounts for the largest part of oil consumption.

OPEC market power is increasing as production of conventional oil outside OPEC has reached a plateau. Oil from tar sands in Canada and elsewhere is available in very large quantities, and is competitive at sustained prices above $40 a barrel. But processing such oil doubles CO_2 emissions on a well-to-wheels basis compared to using conventional oil to fuel transport.

This Round Table assesses the policy instruments available to address oil security and climate change and examines their interaction with measures to manage congestion and mitigate local air pollution. A number of incompatibilities and trade-offs are identified underlining the importance of integrated policy making.

This report includes an examination of the factors that drive oil prices in the short and long term and a discussion of the outlook for oil supply.

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