Vision of evolutions in the petroleum market

Derrick P. Gosselin[1]

Ghent University, Belgium
University of Oxford, Green Templeton College & James Martin Institute, UK

Jan Leysen[2]

Royal Military Academy, Belgium

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[1] Derrick Philippe GOSSELIN is professor at Ghent University. He is as well associate fellow of Green Templeton College and of James Martin Institute for Science and Civilization (Saïd Business School), both at the University of Oxford. In the business world he is corporate vice president strategy & development of Suez. From 2002 until 2007, he was executive vice president of Suez Energy International. He is a member of the Royal Flemish Academy of Belgium (Class of Technical Sciences) and member of the board of the Council of European Technology Academies (Euro-Case).

Ghent University (Universiteit Gent)
Faculty of Economics and Business Administration.
Tweekerkenstraat 2, B-9000 Gent, Belgium
Derrick.Gosselin@UGent.be - derrick.gosselin@gtc.ox.ac.uk - derrick.gosselin@suez.com
Tel: +32 2 510 7405, Tel: +33 1 4006 6425, Fax: +32 2 5107410

[2] Jan LEYSEN is professor at the Royal Military Academy (Belgium). He is head of the Management & Economics Department and Dean of the Faculty of Social and Military Sciences.

Royal Military Academy (Ecole Royale Militaire)
Avenue de la Renaissance 31, B-1000 Brussels, Belgium
Jan.leysen@rma.ac.be

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1. Abstract

Based on an analysis of demand and supply in the current oil market and taking into account which factors, in both the short and long term, will drive future pricing of crude oil, we conclude that in the long term some fundamental and structural changes will occur. Chief amongst these are: a major concentration of oil production in a limited number of countries, a structurally low spare capacity as a percentage of total supply, an increase in production costs and possibly a continuous increase in demand driven by economic growth in developing countries. We conclude by discussing possible evolutions in the oil market based on three future scenarios and discuss the economic consequences of those scenarios.

2. Introduction

On 2nd January 2008, the nominal price of a barrel of crude oil[3] on the New York Mercantile Exchange (NYMEX) reached an historic record during trading of $100[4]. Less than eight years before, in the week of 12th February 1999, the price per barrel on the same NYMEX stood at an historic low of just $9.31 per barrel[5]. Based on one year forward pricing[6] of $75 to $85 for a barrel of crude oil, we may estimate that current prices are affected by a $15 to $25 price speculation. This means nevertheless that oil prices, even without speculation, remain at a high level.

In the short term (0-3 years), price per barrel is determined by the anticipated evolution of demand and supply. This anticipated evolution is highly sensitive to structural limitation, particularly *bottlenecks* in the structural components of the logistical supply chain and *expectations* regarding the evolution of *spare capacity*.

However, in the longer term (10-30 years), more fundamental and structural changes will take place: on the one hand, a shift in the quality of oil being mined, on the other hand an increasing concentration of oil production in a limited number of countries. The Gulf States and Russia will play an increasingly major role in this regard. One thing is already clear: oil will become more expensive - and probably remain expensive - in the longer term.

High oil prices result in significant negative social consequences. This is especially the case for petroleum importing *poor* countries since it leads to a decrease in the countries overall welfare per capita (*e.g.* reduction in buying power due to imported inflation) affecting large parts of the population. In general and on a worldwide scale, high oil prices nearly always (*i.e.* if no social measures are taken) have an effect on the poorest people who depend on gasoline or petrol for transportation to their work and sometimes for

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[3] This is actually the price of a barrel of West Texas Intermediate (WTI) Light Sweet (LS) crude oil as quoted on NYMEX and based on the price settlement hub at Cushing, Oklahoma. WTI is a type of crude oil used as a benchmark in oil pricing and the underlying commodity of NYMEX's oil futures contracts.
[4] See BBC market data on commodities at: http://newsvote.bbc.co.uk/2/shared/fds/hi/business/market_data/commodities/28698/default.stm [last accessed 7th January 2008].
[5] See *e.g.* Energy Information Administration (EIA) at: http://tonto.eia.doe.gov/dnav/pet/hist/rwtcd.htm or Bloomberg at: http://www.bloomberg.com/markets/commodities/energyprices.html [last accessed 3rd January 2008].
[6] The NYMEX one-year forward price, for delivery in December 2008, for a barrel of WTI LS crude oil was $83.40 per barrel on 15th November 2007.

heating. But perhaps a high oil price is not such a bad thing as has been initially assumed. The third oil shock of 2006-2007, characterised by major price volatility on the markets, is forcing us to devise - at speed - scenarios in which oil no longer plays a prominent role. Moreover, this process is being accelerated by a growing awareness of the relationship between fossil fuels, CO_2 emissions, reduced solar energy reflection, global warming and climate change [1].

In this article we attempt, based on a systematic analysis of the current market situation (supply, reserve and demand), to gauge the possible long-term evolution of the petroleum market[7]. We show that oil price calculations using econometric forecasting techniques or market data offer unreliable predictions. We therefore put forward our own vision of possible petroleum market and oil pricing evolutions based on *strategic scenario planning techniques*. This method allows us to consider and prepare for a variety of different possible future petroleum markets, which are not merely future extrapolations of past trends.

The article comprises three parts. In the first part, we analyse and discuss the current petroleum market: the first section outlines the current issues facing the market, the second takes a closer look at the factors that determine supply, the third analyses oil reserves and the fourth and final paragraph deals with an analysis of market demand. In the second part we discuss future evolutions of the petroleum market based on three different future scenarios and discuss the economic effects that each of these scenarios could have. In the final part, we present our conclusions and concerns.

3. Current situation: the only certainty is uncertainty

In 2006, the world consumed almost as much oil as it extracted: around 84.70 million barrels per day. In 2002, consumption stood at 76.96 million barrels per day[1]. However, the demand for energy, which rose by 1.4% a year between 1990 and 2002 [2][3], rose less quickly than worldwide economic growth in Gross Domestic Product (GDP), which is estimated at

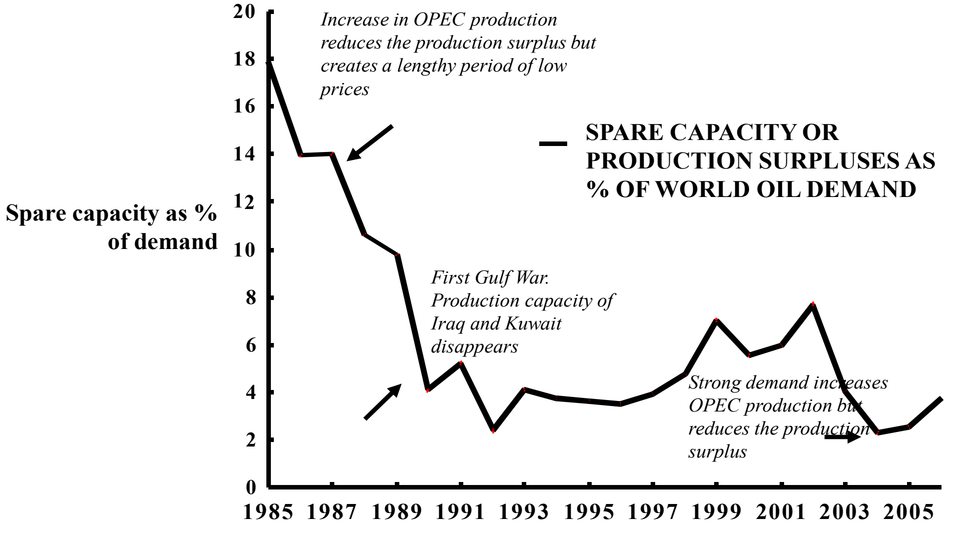
[7] Strictly speaking, we ought to talk about petroleum *markets*, since the price on the world market is determined for each oil field. The most important of these are Brent (North Sea) and West Texas Intermediate (WTI) (US). In general, the WTI price is higher than the Brent price. We cannot therefore talk about a single oil price.

3.4% a year over the same period [4]. This shows that the planet's *energy intensity*[8], particularly with respect to oil, is steadily declining, dropping from 560 litres petroleum equivalent per $1000 of GDP in 1971 to 380 litres in 2002. By 2020, the world average could have dropped beneath the 300-litre level [5]. However, there are significant differences in energy intensity between OECD countries and the emerging economies. For example, in 2005 China consumed 1150 litres per $1000 GDP compared with 180 litres for Europe. This reflects the high-energy intensity of emerging economies, which are consuming large amounts of energy in order to develop their incipient prosperity. Developing prosperity almost always involves strong growth in industrial activities, which is much more energy intensive than an agricultural or service economy.

Emerging economies, which require and consume the most oil in order to drive their growth, are seeing the biggest rise in consumption: between 2002 and 2006, oil consumption in China expanded from 5 to 7 million barrels per day and in the rest of Asia from 8 to 9 million barrels per day. Although the share of oil in China's growth will unquestionably decline sharply, on the strength of that growth China is now poised to become the world's second largest oil consumer after the United States. Global oil production - which in 2002 generated spare capacity of around 2 million barrels per day - is struggling to meet current demand. During 2006, global production (84.6 million barrels per day) was 0.1 million barrels a day too little to satisfy demand. In situations where spare capacity is less than one percent, the market will inevitably react ultra-sensitively to the slightest geopolitical tension or glitch in supply by a major - or even a minor - producer, or to the expectation that this might occur (*figure 1*). OPEC, which was solely responsible for determining world oil prices until 1985, is still (only) producing 33 million barrels per day (all types of oil combined), and is therefore operating close to its production capacity limit[9].

[8] Energy intensity (also known as energy ratio) is a measure of an economy's energy efficiency and thus its energy dependence. It is calculated as the number of *units of energy consumed* (*e.g.* expressed in litres of oil, mega joules, kg or tonne oil equivalent) *per* unit of *Gross Domestic Product* (*e.g.* expressed in US dollars ($) or euro (€)) at constant prices.
[9] *Oil & Gas Journal*, 2006, Worldwide look at reserves and production, 104, 22-23.

Figure 1: *Limited Production Surpluses, Strong Demand and Geopolitical Uncertainties Lead to Big Price Rises*



Source: CERA, 2006; IEA, 2007

4. Analysis of supply: oil is located in high-risk countries

Although there are many reasons why countries may be economically unstable, we can observe that in countries where oil production accounts for a large part of GDP this dependence on raw materials tends to increase in the longer term, which has a *destabilising* effect on the country's prosperity. Over time, this destabilisation is felt politically and socially as well as economically. We observe that the (geo) political behaviour of countries like Iran, Russia and Venezuela is very different when oil prices are high compared with when they are low. Further, the substantial capital flows and profits associated with oil production (*e.g.* $340 billion in 2004 for OPEC countries) affect economic channels and the leading political classes. This can create a climate that is highly conducive to corruption[10]. In addition, oil-producing countries are often so focused on this one activity that they tend

[10] Insufficient separation between public funds and oil revenues is one of the principal causes of non-transparency and thus of potential corruption.

to pay insufficient attention to developing new economic activities and infrastructure.

A combination of the above-mentioned factors means that oil-producing countries often carry a high country risk. The prime example within OPEC is the entire Gulf region, where the legitimacy of ruling regimes is bitterly contested by radical Islamic fundamentalists. Saudi Arabia, the United Arab Emirates, Qatar and Kuwait produced a combined total of almost 18 million barrels per day[11] in 2006. This however takes place under Western protection and with doubts as to the future of the, sometimes fragile Public-Private Partnership (PPP)-controlled monopolistic, National Oil Companies (NOC) responsible for the oil production. In Iraq (2.5 million barrels per day, but with a potential capacity of almost double that amount), the situation is even more complicated and production and transmission facilities will probably face the threat of terrorist attacks for years to come. Iran (4 million barrels per day) raises other doubts and uncertainties: on 8 August 2005, the day the resumption of the Iranian nuclear programme was announced, the petroleum price in New York broke the $64/barrel barrier for the first time. Aside from the Gulf region, the political and economic fragility of countries like Algeria (1.4 million barrels per day), Libya (1.7 million barrels per day), Venezuela (2 to 3 million barrels per day, depending on the quality of the crude oil) and Nigeria (2.4 million barrels per day) should not be overlooked [5][6].

The same analysis applies to oil-producing companies outside OPEC. For example, in the time span of a few years, Russia (9.7 million barrels per day) has developed into an extremely important oil and gas producer and was accused by the IMF in 2006 of having an "addiction to easy money". Indeed, for President Putin's government there is a great temptation to buy social peace, which he did in 2005 by increasing public spending by $13.5 billion. Although this was not a problem for Russia in 2005 - the country having made over $100 billion in oil sales revenue in 2004 - the high oil and gas prices are now transforming Russia into a mono-economy[12] based on oil and gas production, with a significant relationship between growth of oil and gas production and growth of GDP[13]. According to the World Bank, Russia's oil revenues accounted for 25% of its GDP in 2004. The Russian government is also increasingly scaling up, or wresting back,

[11] All production figures that follow are for 2006.
[12] As a result, Gazprom (based on its 2006 turnover figures) is now the third largest company in the world after ExxonMobil and General Electric.
[13] World Bank, 2006, *Russian economic report,* 13 (December).

state control over the biggest oil companies (*e.g.* Transneft, Yukos) and oil and gas reserves for which concessions had been granted (*e.g.* Sakhalin II, Kovykta). By so doing, Russia - like other oil economies - risks becoming overdependent on oil revenues, with the associated risk of slowing down necessary economic reforms (on infrastructure and tax, for instance) by not using resources for structural economic development but instead funding short-term boosts to social well-being (*e.g.* public employment) with revenue generated from unsustainable raw materials.

In the global context outlined above, the reluctance of large petroleum companies to step up their investment and exploration activities is understandable. They are being denied access to whole regions, either by the government (in the form of less efficient National Oil Companies or national monopolies) or by an excessively high country risk. This brings us to the problem of production capacity.

On the supply side, the petroleum sector is characterised by a multitude of risks and a shortage of production and spare capacity. The excessively low oil prices at the end of the 20th century (average of $10 per barrel per day in 1999) led to a shortage of investment capital. This, combined with a degree of inertia on the part of oil companies, has led to insufficient growth in production capacity in recent years. As a result, production, and refinery capacity in particular, is now operating very close to maximum capacity and thus in the inelastic part of the supply curve (see further *figure 3*). In these tense circumstances, it is no surprise that market prices are volatile and that markets are reacting strongly to slight changes in supply or the *expectation* of such changes due to climatic (*e.g.* hurricanes Katrina and Rita) and more particularly (geo) political, economical and social upheavals[14] (*e.g.* assassination of Mrs Benazeer Buthu in Pakistan, the reduction of the Nigerian oil supply and a low dollar exchange rate have pushed the price per barrel crude oil on NYMEX above $100 in January 2008).

[14] For an overview of political, economic and terrorist risks, see *e.g.* Oxford Analytical (http://www.oxan.com) or AON which publishes regular risk maps. Available at: http://www.aon.com/risk_management/terrorism_mitigation/terrorism_risk_map.jsp [last accessed 12th May 2007].

5. Analysis of reserves: will the 21st century be the last petroleum century?

According to data by Nakićenović, Grübler and McDonald [7], the total *proven reserve*[15] of conventional and non-conventional fossil fuels (*i.e.* oil[16], natural gas, coal) is 1282 Gtoe or 53844 EJ[17]. Of this, only 11.7% is conventional oil and 11.0% is conventional natural gas. On the basis of these figures, our fossil fuel supplies at the current rate of consumption will last for around 100 years in the case of oil, 160 years for natural gas and 274 years for coal. We can see that the energy supply from conventional oil will only last between 36 and 59 years at the current rate of consumption or based on the *reserve-to-production* (R/P) ratio [8]. If in addition to these reserves we also take into account *resources*[18] (*e.g.* subeconomic coal, breeder reactor uranium and thorium) and *additional occurrences* (*e.g.* natural gas hydrates and uranium), the Earth probably has enough potential non-renewable energy reserves to meet its energy needs until the end of the 22nd century, assuming energy consumption remains constant. This is not taking into account market price, technological developments, renewable energy or social acceptability. More recent figures from the *Statistical Review of World Energy* [9] indicate that at the end of 2005 the world had a reserve of 1201 billion barrels of (conventional and non-conventional) oil. This figure is regularly revised based on developments in *exploitation techniques*[19] and on market prices. For example, it rose by 10.6% between 1997 and 2004. Exxon Mobil goes further, estimating current reserves at 2200 billion barrels [10]. Depending on which study you follow, this equates to an R/P ratio of 40 to 70 years at the 2006 production rate of 84.6 million barrels per day. In reality, this reserve will probably not last 40 to 70 years, as production is expected to continue rising before peaking at around 120 million barrels per day sometime between 2020 and 2030 [11]. However, these estimates are highly controversial. Optimists point out that during the first oil crisis in 1973 the world had a reserve of less than 41 years. The sharp price rises prompted the discovery of many new oil reserves in the 1970s and 1980s.

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[15] We consider the terms 'reserve', 'economic reserve', 'proven reserve' and 'identified reserve' to be synonyms meaning: the amount of energy that has been discovered and is expected to be economically exploitable. For definitions see: World Petroleum Council (WPC), the Society of Petroleum Engineers (SPE) or the WEA.

[16] Conventional oil comprises oil and liquid petroleum gas (NGL: Natural Gas Liquids); non-conventional oil comprises heavy oils, tar sand oil/bituminous oil, shale oil and coal oil (GTL: Gas-to-Liquids).

[17] Gtoe = Giga (10^9 or billion) tonne oil equivalent - EJ = Exa Joule = 10^{18} Joule.

[18] Resources are energy reserves that have been discovered but are not yet economically (*i.e.* subeconomically) exploitable, and those (economic and subeconomic) that have not yet been discovered.

[19] Current exploitation techniques offer an average extraction efficiency of 35%. It is anticipated that this could be raised to 65-70%, implying a 15% reduction in the estimate of reserves and resources.

Aside from the discoveries themselves, which are progressing more systematically then ever before but at a much slower rate, another factor to be taken into account is the technological progress that has enabled more effective exploitation due to greater *extraction efficiency* [12][13].

Nevertheless, there is no escaping the fact that oil is a finite energy resource. Although it is difficult to estimate today how much of an impact a price of $80-$100 per barrel will have on investment in exploration and exploitation techniques, and although current world oil reserves probably exceed 2000 billion barrels, the fact remains that the earth's crust does not contain an inexhaustible supply of oil. It is probably realistic to assume that by the end of the 21st century humans will be using oil less and less as a primary energy source. According to some experts [14][15][16][17], estimates of reserves and resources are too high and production will probably begin to tail off half a century earlier, around 2050 (*cf.* Hubbert peak[20]), if we fail to curb our mounting oil consumption by more rational and efficient use of energy or by developing alternative primary energy sources. The critical role of technological innovation thus becomes immediately apparent. Other experts [18][19], big petroleum companies [20][21] and recent research by the *US Geological Survey* [22] amongst others suggest that the vision proposed by Campbell [14], Bentley [15] and Simmons [17] is overly pessimistic and that there will be no physical shortage of non-renewable energy before the end of the 22nd century, although temporary shortages may occur.

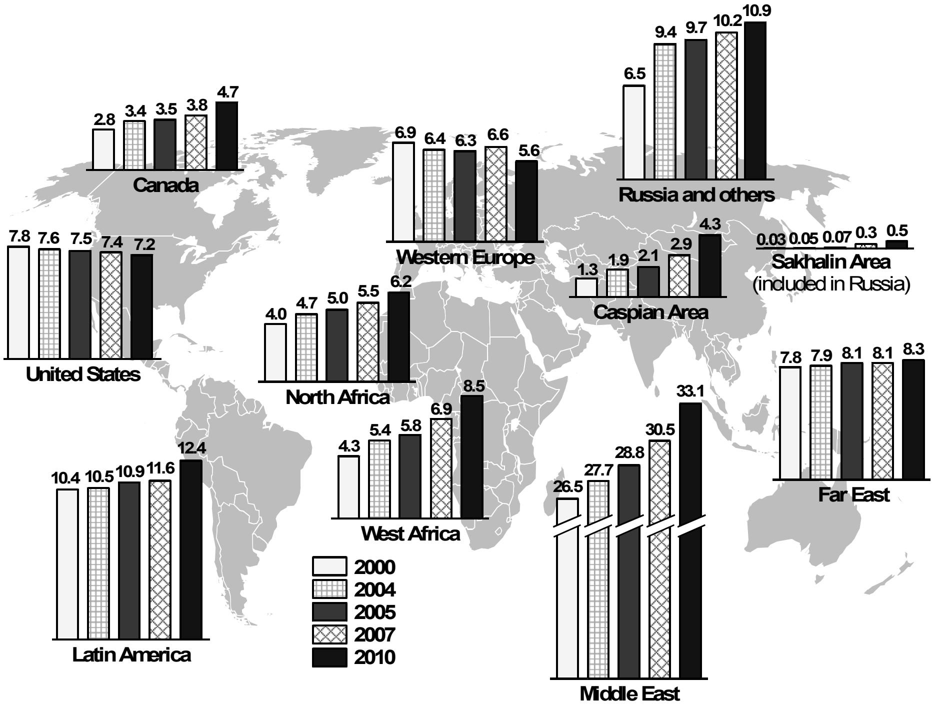
If we fail, or are too slow, to develop alternatives, in addition to the potential implications of the Hubbert peak another transitional problem will arise, namely the geographical concentration of conventional oil reserves. At the end of 2005, OPEC estimated that it controlled a reserve of 913 billion barrels. This equates to 76.02% of global oil stocks, based on the estimated world oil reserve of 1201 billion barrels [22]. Moreover, 65.0% of world reserves are located in the Middle East (Saudi Arabia, for example, has a reserve of 264 billion barrels). Conventional production regions[21] such as

[20] In 1956, Dr Marion King Hubbert was the first person to correctly predict the evolution of US oil production using a mathematical model based on a Gauss curve. He concluded from this that the production of an oil field (but also of a region, a country or the world) would evolve along a Gauss curve. The top of the Gauss curve corresponds to the moment of maximum oil production. This is known as the *Hubbert peak*. Global attainment of the Hubbert peak is seen as the end of the oil age and is theoretically expected to occur before 2015. However, based on recent empirical research, a production plateau - rather than a production peak - is now anticipated, which could push back the production peak by some 20 to 30 years.

[21] We do not take into account non-conventional oil reserves such as extra heavy bituminous oils from the Orinoco (Venezuela) or tar sand oil from Alberta (Canada).

Europe, Africa and Latin America will probably have used up their reserves by 2025-2035 (*figure 2*).

Figure 2: *Shift in World Production Capacity (million barrels per day)*



Source: CERA Cambridge Energy Research Associates 2006

This is only 20 to 30 years away! Leaving aside Russia, the world will therefore be almost completely dependent for its supply of conventional (and generally cheap-to-extract) oil on the Arabian/Persian Gulf (*table 1*) - a geopolitically unstable region at the heart of the biggest socio-religious issue of the start of the 21st century: the place of Islam in our societies.

Table 1: Increase in concentration of production capacity (million barrels per day)

Rank	Country	1995	2005	2015
1	Saudi Arabia	10.8	12.6	13.0
2	Russia	6.2	9.6	11.5
3	Iran	3.8	4.3	5.7
4	Iraq	2.1	2.6	5.5
5	Canada	2.4	3.5	5.3
6	Venezuela	3.0	3.0	4.5
7	UAE	2.7	3.1	3.9
8	Kuwait	1.8	2.9	3.7
9	Nigeria	2.1	2.9	3.6
10	Kazakhstan	0.4	1.2	3.1
11	Algeria	1.4	2.3	2.9
12	Libya	1.4	2.0	2.8
13	Brazil	0.8	1.8	2.6
14	Angola	0.6	1.2	2.3
15	Azerbaijan	0.2	0.5	1.0
	Total Top 15 (10^6 barrels/day)	**39.5**	**53.5**	**71.5**
	% global production capacity	**55 %**	**61 %**	**69 %**

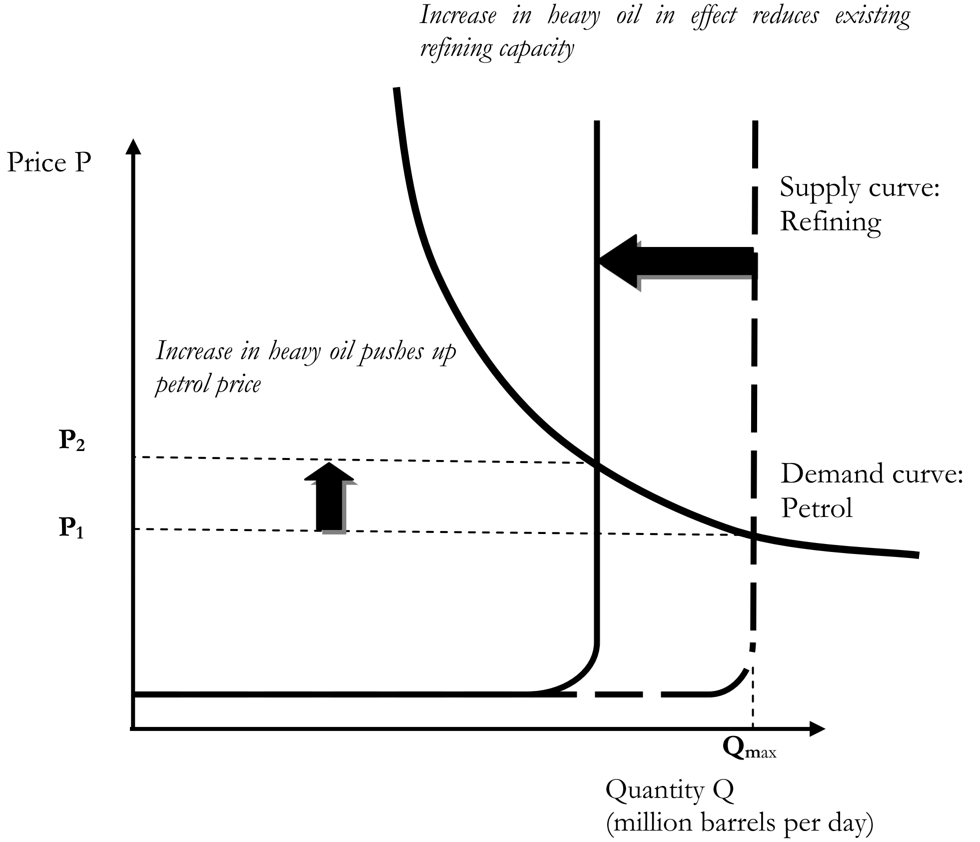
Source: World Energy Council 2004, IEA - World Energy Outlook 2007

However, within the next five to 10 years, the decisive factor influencing supply will not be increased concentration or limited reserves but rather the capacity-limiting element in the supply chain. Since 2005, this element has been refining capacity. Two causes underlie this fact. Firstly, more and more newly tapped oil fields are yielding hard crude oil. This probably indicates that stocks of cheap, high-quality oil have been virtually exhausted. This trend will be reinforced by the eventual exploitation of non-conventional oil fields such as those containing tar sand and oil sand, heavy bituminous oils and oil shales[22] [23][24], since all of these additional fields also yield heavy oil. This evolution will lead to a reduction in the average quality of crude oil due to an increase in the ratio between heavy and light crudes. As a result,

[22] According to the IEA, oil shale represented 1.4% of global production or 1 million barrels per day in 2004. The IEA expects this to increase to 3.0% by 2010.

refinery infrastructure will become less productive[23]. Secondly, refining capacity has remained almost constant in recent years due to low oil market prices in the 1990s. Both of these factors have, in effect, caused a drop in existing refining capacity (*figure 3*), which if demand remains constant will lead to price rises unless more is invested in capacity (*i.e.* the inelastic region of the supply curve). Note also that the lower quality of heavy oil will translate into increased CO_2 emissions, a lower energy value, higher exploitation costs and a greater energy requirement to convert heavy crude oil into useable energy.

Figure 3: *Heavier Oil has the Effect of Reducing Refining Capacity*



[23] More hydrocarbon compounds are needed to refine heavy oil compared with light oil (different stoechiometric ratio), meaning a 26% theoretical drop in the productivity of refining capacity. This explains why heavy crude is traded at 70-60% the price of light crude.

6. Analysis of market demand: can we limit demand?

The history of petroleum is fascinating. In a relatively short period - 150 years at most - this fuel has become indispensable due to modern production and consumption habits. Petroleum has emerged as one of the cornerstones of our economic prosperity over the past 30 years [25]. We know that our oil reserves are limited and yet with every new oil crisis - and the one in 2005-2006 where oil price went from $30 to $65 per barrel to reach eventually more than $100 et the beginning of 2008 can safely be termed an oil shock - the world reels in disbelief at the scale of a problem which for decades it has tried to ignore. The warning light was flashing as early as 1974. All, mainly rich and oil-dependent OECD countries, attempted to reduce their dependence on OPEC by cutting their oil consumption (energy intensity). They did this by reducing or replacing their consumption of oil as a primary energy source: reducing it by more rational and efficient use of energy (insulation, more efficient engines and machinery, etc.), replacing it by converting to nuclear energy and natural gas for power generation and natural gas for heating. Some developing countries such as Brazil used cane sugar alcohol as an alternative to petrol.

The reverse oil crisis of the 1990s led to some *rational use of energy* (RUE) solutions being economically sidelined. From an RUE perspective, prices of $65-$100 per barrel in 2006-2007 are arguably more of an advantage than a disadvantage. Indeed, assuming an estimated worldwide energy consumption of 11429 Mtoe per year[24] or 400 EJ per year in 2005 [26][27][28], oil was still the most used primary energy source at 37.3%. Over 50 % of this oil is used by the transport sector, where derivatives (*i.e.* diesel, kerosene, petrol) predominate. With the world now used to travelling as and when it pleases, it is here that the stranglehold of petroleum is most keenly felt. However, the use of other primary non-renewable energy sources such as coal, natural gas and nuclear energy is also problematic.

Coal will be available in large quantities and evenly distributed reserves for at least another 250 years. This is notably the case in the United States, Russia, India and China. China and India depended on coal for over 75% of their power production and the US for almost 50% (which immediately explains why these three countries did not sign the Kyoto Protocol). However, using coal or lignite to generate electricity still involves either a

[24] Mtoe = Mega (10^6 or million) tonne oil equivalent = 0.0209 million barrels per day = 42 PJ (PJ = Peta Joule = 10^{15} Joule).

high environmental cost or major investment. As regards the environmental cost, 41.6 billion tonne of CO_2 equivalent or $GtCO_2e$[25] was produced worldwide in the year 2000 [29]. Of this, 24.7 $GtCO_2e$ in 2000 (and 26.6 $GtCO_2e$ in 2005) came from burning fossil fuels [30]. More specifically, 10.3 $GtCO_2e$ came from power generation, of which 6.6 $GtCO_2e$ was from coal-fired generation [31][32]. Within the 42 $GtCO_2e$ of annual emissions, coal-fired electricity generation therefore accounts for almost 16% of all *Greenhouse-Gas* (GHG) emissions worldwide. Moreover, the total investment cost (TIC) of a modern coal-fired power station, though admittedly dependent on the technology used (€1600 to €2100/kW) and the presence or absence of CO_2 capture (€2800/kW for a 500-MW power station), may exceed that of a nuclear power station (€2100/kW for a 1600 MWe PWR type reactor *e.g.* Areva EPR) [33][34][35].

With natural gas the issue of transmission is key, since natural gas, like oil, is not found in the regions where it is consumed. The transmission of natural gas in liquid form (*i.e.* Liquefied Natural Gas LNG) is no easy matter. Crossing oceans requires an expensive logistical chain, from liquefaction through methane tankers to regasification[26]. The advantage of natural gas over oil is that it is more plentiful and better distributed geographically, although large reserves are often found with oil (*e.g.* the extensive gas reserves in Russia, Iran, Qatar, Bahrain and Yemen) and therefore guaranteeing continuity of supply may be an issue as well.

Finally, nuclear energy probably offers the most potential of all. Proven (economic) uranium and thorium reserves could sustain current production levels for at least another 50 years and possibly up to several centuries if we include the nuclear fuel generated by breeder reactors [36][37][38]. On the minus side are the associated safety risks and the problem of processing

[25] $GtCO_2e$ = Giga (10^9 or billion) tonne CO_2 equivalent. In 2000, the 41.6 $GtCO_2e$ consisted of: 77% carbon dioxide (CO_2), 14% methane (CH_4), 8% nitrogen monoxide or laughing gas (N_2O) and 1% F gases (*e.g.* sulphur hexafluoride (SF_6), perfluorocarbons (PFCs), and hydrofluorocarbons (HFCs)).
CO_2 is used as the standard for determining the Global Warming Potential (GWP) of other greenhouse gases. CO_2 has a GWP index of 1 over a period of 100 years. The CO_2e or *carbon dioxide equivalent* is the weight (usually expressed in million metric tonnes) of a greenhouse gas multiplied by its GWP index. CO_2e is therefore the amount of CO_2 that would cause the same GWP over a period of 100 years as the amount of greenhouse gas. For example, the emission of 1 million tonnes (Mt) of methane (GPW = 21) or nitrogen monoxide (GWP = 310) is 'equivalent' to the emission of 21 $MtCO_2$ and 310 $MtCO_2$ respectively, in terms of its warming effect.
[26] The cost of an LNG (Liquefied Natural Gas) chain from exploration & production, liquefaction, transmission and regasification is around $7-9 billion for a capacity of 5 million tonnes of LNG/year. For reference: 1 million tonnes of LNG is enough to supply a modern 1000-MW gas-fired power station (CCGT) for one year.

highly radioactive waste. Industrialised countries are worried about accidents, while with developing countries there is a fear of potential military use of nuclear energy (in Iran, North Korea, Pakistan, India, etc.). This has been apparent since 2006 in the ongoing ambiguities surrounding the Iranian nuclear programme - one of the causes, incidentally, of the current oil crisis.

With hydroelectric power, development potential is rather limited and the Three Gorges Dam on the Yangtze river in China seems likely to be the last large-scale hydroelectric scheme for some time. Moreover, possible global warming may affect water reserves stored in the snow and glaciers of the Andes and Himalayas. These water reserves feed the reservoirs of hydroelectric power stations, which are used extensively in Latin America (Brazil, for instance, generates over 75% of its electricity at hydropower plants), China and northern India.

In theory, the other conventional non-renewable energy sources (*i.e.* coal, gas and uranium) should suffice to meet humanity's needs in the 21st century and to offset the problem of depleting oil stocks[27]. However, two issues require special attention: the American consumption model and energy consumption in China and India.

In 2004, oil consumption in the United States (US) was 20.5 million barrels per day, almost a quarter of total world production. Of this, 65.0% (13.24 million barrels per day) was used for *transport* [39]. The situation is comparable, if less pronounced, in most OECD countries. Furthermore, oil in the US is barely taxed and is therefore much cheaper than in Europe. Even with oil at $95 per barrel (last quarter 2007), US consumers pay on average just $ 0.82 or €0.58 a litre (*i.e.* $3.1 a gallon[28]) compared with €1.3-1.8 elsewhere in the world. As a result, American consumers are subject to few consumption reduction measures during one of the three major consumption periods: the spring driving season[29]. As a result, US energy demand has continued to rise steadily: by 2.0% in 2003, 2.5% in 2004 and 1.8% in 2005 [40]. Over the past three years, worldwide oil demand has

[27] *cf. supra*: lifetime of 274 years for coal, 160 years for natural gas and over 300 years for nuclear fuel, including fuel from breeder reactors.
[28] 1 gallon = 3.79 litres. Average US retail price on 27th December 2007: http://www.eia.doe.gov/oil_gas/petroleum/data_publications/wrgp/mogas_home_page.html [last accessed 3rd January 2008].
[29] The other two periods are the *heating season* in winter, which sees heavy demand for coal and gas, and the *cooling season* in summer, when air-conditioning is switched on across the country and the demand for electricity, and hence coal and natural gas, rockets.

increased by 6 million barrels per day. Of this, 4 million barrels per day were for developing countries (including 2 million barrels/day for China) and 2 million barrels/day were for the OECD countries (including 1 million barrels/day for the US). The American model, which is now firmly entrenched (*cf.* President Bush's[30] arguments, as presented in 2001, for not signing the Kyoto Protocol), is a major environmental liability for the planet. Even so, the US has since 2001 modified their position by acknowledging at the December 2007 United Nations conference on climate change in Bali the existence of a climate change problem, no commitments have been taken or accepted yet: neither on CO_2 reduction objectives nor on a timetable to reach any reduction target. Stanislaw [41] formulates the US environmental liability as the *2-5-25-25* challenge. The US has only 2% of the world's reserves and 5% of the world's population, yet consumes 25% of core non-renewable fossil primary energy sources (*i.e.* oil, gas and coal) and accounts for 25% of annual global CO_2 emissions. This is of course owing to its high GDP, yet the gulf between the US and the rest of the world clearly points to a global imbalance. According to the World Bank, 2.7 billion people around the world live on under $2 a day[31]. These people have no access to electricity, water and sanitary or other essential services, but are increasingly aware of Western lifestyles and the economic imbalance between developed and developing countries.

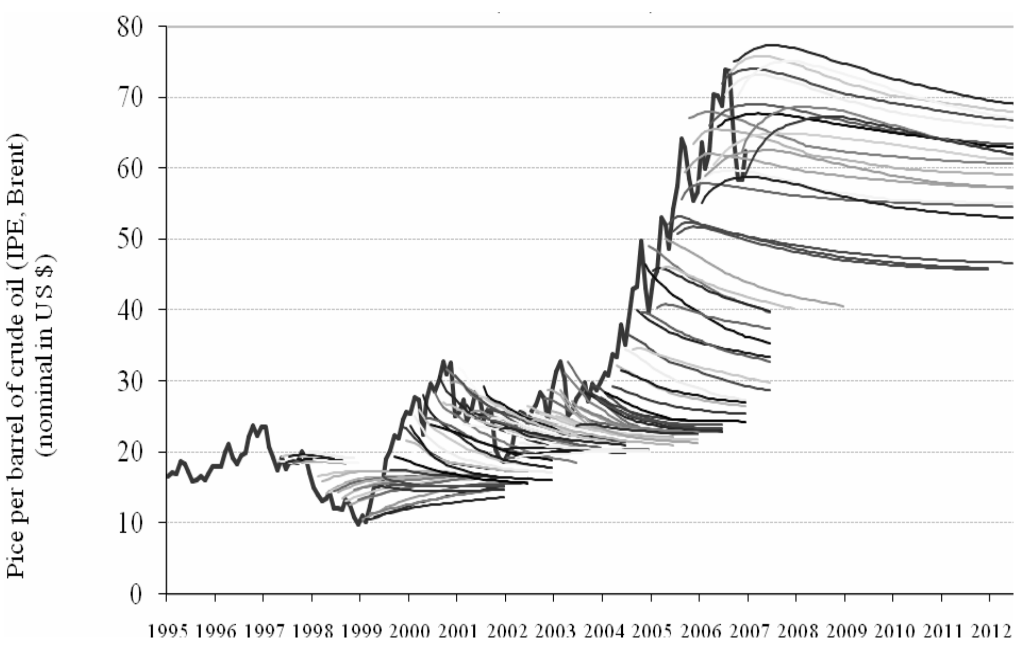
In 1975, China was not even listed as an oil-consuming nation, yet by 2005, it had become the second biggest oil consumer in the world. China's oil needs, like those of India, are set to increase further between 2005 and 2015. According to United Nations projections[32], China's population will rise by 77 million and India's by 157 million between 2005 and 2015. By 2015, the IEA [42] estimates that their energy consumption will have doubled to trebled and that both countries will need to import 70-80% of their required energy. Unless specific steps are taken, consumption patterns in the US, China and India will create continued demand for oil in the next 20 years. Worldwide oil consumption is thus forecast to reach 120 million barrels per day between 2020 and 2030 [42].

[30] Bush, G.W., 13th March 2001, Letter from the President to Senators Hagel, Helms, Craig, and Roberts. http://www.whitehouse.gov/news/releases/2001/03/20010314.html [last accessed 2nd January 2008].
[31] World Bank PovertyNet – http://www.worldbank.org/poverty [last accessed 28th December 2007].
[32] World Population Prospect, 2004 revision, United Nations.

7. Possible evolutions of the petroleum market: a scenario approach

The complexity of demand and supply on the petroleum market makes it extremely difficult, if not impossible (*figure 4*), to reliably predict the future evolution of this market using econometric forecasting techniques or (market) modelling. The number of exogenous and endogenous variables is too great and their reactions and movements too uncertain to calculate a sufficiently reliable forecast (*i.e.* with a small standard deviation) of the future evolution of key figures in the petroleum market, based on historical data, using econometric extrapolation techniques [43].

Figure 4: *Spot Price vs. Forward Prices of Brent Crude Oil (1997 – 2006)*



To support this argument, we examined the average monthly spot price for a barrel of Brent crude oil[33] together with the associated month-end forward price curve, on the ICE Futures exchange (formerly the International

[33] The spot and forward prices are nominal prices in US dollar per barrel of Brent crude oil on the ICE Futures (formerly the International Petroleum Exchange IPE) in London.

Petroleum Exchange IPE) in London over the period 1997-2006 (*figure 4*). According to financial theory, these forward price curves are the best and most comprehensive information available on the market at any time. As *figure 4* shows, virtually all of the forward price curves fail to predict actual oil prices (price level or trend) with any degree of accuracy. In fact, we can go further and say that systematic errors occur as a result of trusting what we term *anchor prices*, *i.e.* forward price levels that converge at a relatively stable, anticipated, future market price around which market prices are, as it were, anchored. Indeed, it can sometimes be several years before the market is ready to revise its forecasts or expectations regarding anticipated price level (*e.g.* $20 price level per barrel - *figure 4*).

An alternative method to econometric forecasting, one that can be used in complex situations where the past displays insufficient continuity to predict the future using extrapolation, is *strategic scenario planning*[34] [44]. Econometric forecasting techniques are implicitly based on factors that are assumed to display continuity with the future. Indeed, this is a pre-condition for applying extrapolation with any degree of accuracy. The disadvantage of these techniques, therefore, is their assumption that the future displays a significant degree of continuity with the past and is thus more predictable than is actually the case.

In contrast to econometric forecasting techniques, scenario planning does not aim to forecast the 'correct' or 'probable' future but rather aims, based on a thorough analysis, to arrive at a better and systematic understanding of the main factors that may shape the future. Because scenario planning is based on uncertainties formulated around strategic questions, it enables the future - or possible futures - to be examined in a more flexible way. Opportunities and risks can therefore be identified early on and discontinuous changes reacted to more quickly because the relationship between different developments is understood more immediately, based on a coherent and considered vision of the future. For a methodological discussion of scenario planning techniques, see the article by Bradfield, Wright, Burt, Cairns [45] and by Van Der Heijden [46].

In 2005 and 2006, in partnership with *Cambridge Energy Research Associates* [47] and the *James Martin Institute for Science and Civilization* (University of

[34] Another common technique for long-tem forecasting is the Delphi method developed by the Rand Corporation. An extensive literature can be found on the Rand Corporation website: http://www.rand.org [last accessed 4th January 2008].

Oxford), three in-depth scenarios were developed concerning possible evolutions of the petroleum market. Sixty-eight companies worldwide took part in this research and interviews were held with 22 experts. In accordance with standard practice in scenario development, three *strategic uncertainties* were selected following in-depth preparatory research. These strategic uncertainties are important as they could fundamentally affect future market developments in the next two decades. The three strategic uncertainties, formulated in terms of strategic questions and possible answers to them, resulted in three different future market evolutions or scenarios, which we will abbreviate as (1) *Asian Phoenix*, (2) *Break Point* and (3) *Global Fissures*.

For each of the scenarios, we discuss the strategic uncertainties and strategic questions in turn and briefly describe the corresponding market scenario. Note that all prices given below are *nominal*. The principal key figures for each of the three scenarios are summarised in *table 2*.

Table 2: Summary of key figures for each scenario

Key figures	Asian Phoenix	Break Point	Global Fissures
Economic Growth			
Growth in GDP/PPP (%)			
World	4.0	3.9	2.9
OECD Asia	2.4	1.8	1.5
China	6.9	5.9	5.0
Europe	1.5	2.2	0.9
US	2.9	3.0	1.9
Primary Energy			
Growth in demand for primary energy (%)	2.3	1.9	1.6
Percentage change in global share			
Oil	(6.0)	(8.0)	(4.0)
Gas	2.0	2.0	3.0
Coal	3.0	3.0	2.0
Nuclear	(1.0)	0.0	(2.0)
Renewable energy	2.0	3.0	1.0

Key figures	**Asian Phoenix**	**Break Point**	**Global Fissures**
Oil Markets			
Real oil price per barrel (max/min for WTI)	$68 / $42	$96 / $40	$62 / $16
Nominal oil price per barrel (max/min for WTI)	$81 / $49	$120 / $73	$64 / $19
Global growth in demand for oil (%)	1.6	1.0	1.1
Global demand for oil (million barrels/day)			
2010	92	88	90
2020	108	95	100
2030	124	108	110
Global production (million barrels/day)			
2010	97	88	96
2020	111	101	104
2030	127	114	115
Share of non-conventional oil (%)	11	15	9
CO_2 Emission			
Growth in CO_2 emission (%)	2.3	1.7	1.6
CO_2 emission through energy in 2030 ($GtCO_2e$)	41.0	35.8	35.0

Source: CERA 2006, James Martin Institute, University of Oxford

7.1. Scenario 1: Asian Phoenix

This scenario takes as its strategic uncertainty growth in Asia and assumes that Asia will succeed in sustaining its economic growth in the coming years. This raises two specific strategic questions:

- How would continuous economic development in Asia affect the global balance of power and the world order?
- How will the resulting geopolitical changes affect the energy markets and competition for access to primary energy sources?

The answers to these questions form a future scenario in which the economic centre of gravity shifts to Asia. In such a scenario, both Europe and the US could lose their economic dominance. This scenario leads to a global demand of 124 million barrels per day in 2030, an increase of 40 million barrels per day compared with 2005. The average nominal price of *West Texas Intermediate* (WTI) is $64 per barrel of crude over the period 2006-2030. The top price of $81 per barrel occurs in 2030 and the bottom price of $42 sometime around 2013. From 2013, prices are systematically driven up by instability in the Middle East, continuous strong demand in Asia and only a gradual increase in production capacity. However, the price will not exceed $100 per barrel because in this scenario a major increase in non-conventional fuel production is anticipated and a significant increase in efficiency due to high oil prices. As a result, the energy intensity of the global economy will decline and eventually oil prices will level off, albeit at a high level.

7.2. Scenario 2: Break Point

This scenario is based on the strategic uncertainty surrounding the price of oil and assumes that oil prices can be sustained at a high level. This results in the following specific strategic questions:

- What conditions would serve to keep oil prices high over a long period?
- What would be the long-term impact of such high-energy prices?
- In the event of sustained high-energy prices, could technology and changed demand eventually lead to a drop in prices, thereby possibly dislodging oil from its primary position?

The answers to these questions lead to a future scenario in which sustained high oil prices stimulate the development of substitute products. Oil loses its monopoly as a transport fuel, which eventually brings prices down. In this scenario, the oil markets are strained between 2007 and 2015. The average nominal price for conventional crude oil (WTI) climbs to $120 per barrel in 2016, then falls gradually to $80 per barrel in 2030. This steep price rise through to 2016 is owing to production limitations, which keep spare capacity low. Post 2016, the price falls steadily as a result of two factors: on the one hand, falling demand due to increased efficiency among end users; on the other hand, a relative rise in supply compared with demand due to an increase in the production capacity of both conventional and non-conventional oil. Both trends are driven by the historically high oil prices.

7.3. Scenario 3: Global Fissures

This scenario is based on the strategic uncertainty surrounding continued economic globalisation and assumes that such globalisation could end. This results in the following specific strategic questions:

- It is generally assumed that globalisation of the economy (*i.e.* the free exchange of goods, services and people between countries) is an unstoppable force that will continue to expand. Nevertheless, is it conceivable that global economic integration will come to an end?

- Are there political limits to globalisation?

- How would a sustained global recession and an ensuing increase in trade protectionism affect the global energy markets?

The answers to these questions spawn a future scenario in which extensive anti-globalisation and anti-trade policy combined with political tensions and security issues determine the future. This eventually leads to weak economic growth and ultimately to low energy prices. In this scenario, the oil price falls in around 2011 to $19 per barrel of crude oil. This price drop is the consequence of weak economic growth and the increase in capacity-expanding investment, which will become operational just before prices fall, thereby keeping prices low. The oil price does not remain at this low level; it climbs back to $40 per barrel due to several years of mounting demand sometime around 2017. Conventional oil remains important because investment in non-conventional oil[35] will have declined due to the low prices.

[35] Non-conventional oils comprise: extra heavy oil, tar sand oil, shale oil, biofuels and Fischer-Tropsch Liquids (FTLs). FTLs include the Gas-to-Liquids (GTL) and Coal-to-Liquids (CTL).

8. A longer-term vision: attempted synthesis

Based on the market analysis outlined above and insights gained from the various strategic scenarios, we can draw a number of conclusions that will enable us to assess future evolutions on the petroleum market based on a broader vision. We structure this vision around nine statements.

1. *Political attention will remain heavily focused on energy issues in the coming years*. We believe that discussions about energy (*e.g.* alternative energy sources, energy efficiency, economic implications, security of supply, environmental protection), will remain high on the political agenda of oil-consuming countries (especially the big ones) for many years to come. This will probably remain the case even if oil prices fall. For although discussions on oil demand and supply heat up when oil prices are high, the reasons underlying oil pricing go far beyond a lack of spare capacity: they are also affected by the political vision of both consuming and oil-producing countries. Heavy political focus will probably lead to a more complex environment, as a result of political measures such as subsidies, taxes and trade agreements. This will also further complicate the geopolitical situation. Indeed, political decision-making in countries that import a lot of energy will differ from that or countries that export energy. Importing countries will focus on guarantees of supply continuity and efficiency-enhancing measures, while oil-exporting countries will be geared mainly towards ensuring continuity of demand [48].

2. *Asia, in particular China and India, will drive the growth of the global economy*. In all scenarios, Asia is behind the growth in oil demand. This trend will affect all economic players. Asian demand is creating the need for more oil and electricity and stimulating demand for infrastructure to bring this supply to its markets. Asia is also becoming a key player in consumption of and demand for both oil and gas. As a result, we believe that Asian companies will also become more involved in joint ventures, takeovers and mergers. Increasing energy consumption in Asia is a sign of increasing economic power, something which will also be reflected politically at a global level.

3. *Increase in energy efficiency*. The combination of technology, government policy and market demand will spearhead a drive towards greater energy efficiency. As a result, we believe that the energy intensity of the OECD countries, China and India will continue to decline. For a detailed study of possible energy productivity improvements by industrial sector, see *e.g.* the McKinsey Global Institute report [49].

4. *Increase in use of biofuels*. The increase in ethanol and biodiesel will probably result in a greater correlation between agricultural prices (of maize and sugar cane) and the price of related fuels. This will also have a bearing on the price of agricultural land.

5. *End users must have a clear strategy for dealing with these changing market conditions*. We think that the global fuel mix will become more complex, an example being the non-traditional fuels, which will gain in importance. The ability to adapt quickly to changing market conditions could mean significant advantages, assuming that the cost of flexibility is not too high. After all, one way that exporting countries are seeking to achieve demand stability is by offering long-term contracts, with little possibilities for arbitrage in the short term.

6. *Fischer-Tropsch Liquids*[36] *(FTLs) will become an important alternative component*. We anticipate an increase in the use of gas and coal (via the Fischer-Tropsch process) to manufacture liquid fuels. The use of FTLs varies widely from scenario to scenario but will increase significantly due either to political measures or market demand. This increasing interrelation between gas, coal and oil will probably not affect day-to-day price formation but will have an impact on longer-term investment choices.

7. *Increase in conversion technology and infrastructure*. In all scenarios, the share of non-conventional oil expands[16]. This will mean additional importance for the various conversion technologies, which have hitherto been of minor significance to the energy markets. This will create the need for additional infrastructure, in particular

[36] The Fischer-Tropsch process is a catalyst reaction (using iron and cobalt) in which carbon monoxide CO and hydrogen H_2 are converted into liquid hydrocarbons C_nH_{2n+2}. One purpose of the process is to produce synthetic petroleum substitutes.

railway lines and road, in order to transport the raw materials (cereal crops and cane sugar) needed to produce ethanol. For the Coal-to-Liquids (CTL), a subset of Fischer-Tropsch Liquids, rail and pipelines will tend to be used.

8. *The speed at which energy markets can change will be limited.* The size of the existing energy markets is such that it will take time to develop alternatives to traditional fossil fuels. Within a timeframe of 10 to 20 years, increased technological innovation could well have a significant impact on the availability of non-traditional fuels.

9. *Hydrogen will not emerge as a significant alternative energy carrier.* Hydrogen (H_2) has some major challenges to overcome before it can make a significant contribution as an energy carrier. H_2 is not a primary energy source itself but, like electricity, is generated from primary energy sources. Although niche markets for H_2 could develop, such as fuel for transport or energy generation, we do not believe that hydrogen will have a significant influence on the demand for fossil fuels before 2030. One of the reasons for this is the low density per volume unit of H_2, which means that either high compression or liquefaction is necessary for economic use and distribution. This presents a major challenge in terms of the storage, distribution and trading of hydrogen. A further challenge is the development of production technology. Although a mini-hydrogen economy does already exist, this is mainly limited to the petrochemical sector which produces H_2 from fossil fuels, principally gas. Building a hydrogen economy based on fossil fuel is not an obvious long-term solution to the energy problem. For a technological overview and discussion of the technological challenges involved in developing a hydrogen economy, see the BACAS[37] [50] report.

[37] Report available at http://www.kvab.be/downloads/CAWET/Hydrogen_energycarrier.pdf [last accessed 31st December 2007].

9. Conclusion

We are probably on the verge of fundamental changes in the way our prosperity and well-being are created and their association with conventional oil. The difficult and complex interaction and interdependence between *energy markets*, *technology*, *politics* and *environment*, and their impact on prosperity and well-being are likely to be one of the biggest geopolitical issues and challenges of coming decades.

Thirty-four years ago, on 18 October 1973, the OAPEC[38] decided, due to a crisis in the Middle East (Yom Kippur war), to raise the price per barrel of crude oil by 70%. In the space of a few days, the price per barrel of crude rose from around $3 to $5, to reach $11 per barrel three months later in early 1974. This prompted responses such as car-free Sundays, the introduction of daylight savings time, speed restrictions and also a gradual switch to nuclear energy and natural gas and the launch of R&D projects to develop alternative (sustainable) energy sources (*e.g.* solar energy, wind energy) and energy saving through rational and efficient use of energy. The aim of all these actions was to increase *energy productivity*[39] or to reduce energy intensity, and more specifically diminish dependence on oil as a source of energy, as quickly as possible. Three decades on and we are facing another energy crisis; it too has doubled prices and it too originated with a crisis in the Middle East. However, the background to the current crisis is more volatile, unpredictable and complex than in 1973.

In 1973, neither China nor India were major oil consumers, whereas today they are poised to become the biggest consumers of the next few decades. Russia in 2007 is one of the biggest oil and gas producers in the world and is in the process of renationalising its energy sources in order to enhance its geopolitical role. Perhaps the most important development of all is the unnoticed shift in energy geography. The axis comprising Saudi Arabia, the Caspian Sea, Siberia and Canada is set to become the centre of gravity of 21st century oil production, and it is partially on this axis that most 'democratisation projects' are to be found. Moreover, as we move into the future we will have to reckon not only with an oil challenge but with a gas

[38] OAPEC: *Organization of Arab Petroleum Exporting Countries*. Controls over 50% of world oil reserves. Forms the core of OPEC.

[39] We define *energy productivity* of GDP as the reverse of *energy intensity*. Energy productivity (also known as 'energy efficiency') measures the amount of goods and services that can be produced with a given energy input (production per unit of energy). Energy intensity, on the other hand, measures the necessary energy per unit of GDP.

challenge too. Finally, we should not forget the issue of CO_2 emissions and associated effect on global warming. The latter will spark an in-depth discussion of future energy policy and the timeframe within which solutions will need to be found, taking into account the fact that: at the start of the 21st century we do not have effective global or supranational decision-making structures for solving global problems; it is hard to assess how soon researchers will be able to develop innovative alternatives; and it is highly likely that worldwide energy demand could rise by 2 % annually over the next 15 years.

However, the current energy crisis could be a catalyst for a new period of market-driven innovation in: alternative energy, energy conservation, sustainable energy development and international cooperation. This means that in the coming decades *energy productivity* will become a key issue for consumers, companies and governments alike. Indeed, rational use of energy is so important that it could reduce the growth in worldwide energy demand from 2.2% to 0.6% over the next 15 years [51].

We have wasted over 30 years by failing to invest intensively enough in energy productivity. We probably need more than two generations of highly talented individuals to find a solution for a) the transition from a global economy based on gas, coal and oil to one based on sustainable and alternative energy sources and b) an economy that uses energy in a fundamentally more efficient way. This in turn immediately raises the issue of (technical) skills management.

The major challenge remains how to effect the transition from today's economy to the more sustainably and efficiently driven economy of the future. It will mean reducing our dependence on fossil fuels and making fundamental transformations geared toward the use of new energy sources, and doing so at a global level. This transformation may occur in bursts or it may occur gradually. Depending on this, we will face different possible future scenarios and different economic prospects.

However, there is also an increasing realisation that what we are dealing with here is a special category of problems, known as *wicked problems* [52]. Such problems have no short-term solutions due to insufficient data. Solutions can only be found in the longer term by means of joint consultation with specialists in each of the four areas mentioned and by focusing on *technological innovation*. A characteristic of such problems is that they cannot be solved by conventional policy methods like efficiency management, setting targets or other rational decision-making, partly because too much information is lacking. The realisation that energy in the context of a macro approach is an *intractable problem* may help to eliminate naive solutions and create a more realistic pattern of expectation regarding possible solutions. We believe that establishing a *supranational coordination structure* is one of the necessary conditions for reaching a solution.

Decision-making in such complex situations requires insights that strategic scenario planning could possibly help to create. Using this technique enables choices and expectations to be mapped more effectively. As a result, we could - through the decisions that we take, or do not take, today - potentially ensure that, of all the possible futures ahead of us, those that we do not choose are not simply allowed to happen.

We believe it is critical that (global) enterprises whose profitability is heavily dependent on the evolution of oil prices (*e.g.* energy sector, power producers, transport sector, chemical industry) develop the ability to undertake *strategic discussions* in which, based on strategic scenarios, the robustness of strategic decisions (*e.g.* takeovers, capacity investments) are assessed based on their risk profile and performance in each of the scenarios. Key to this new way of strategic thinking is the need to take into account several different visions of the future, thereby enhancing the company's strategic flexibility: an asset that will set the company apart and thus constitute a competitive advantage [53].

It is not possible to predict the future but it *is* possible to have a vision of a desired future which could, by adopting a proactive approach, potentially become reality. As *Baltasar Gracián* (1601-1658) put it: "It is a great piece of skill to know how to guide your luck even while waiting for it."

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