International Energy Workshop, June 2001, IIASA, Laxemburg, Austria

1st Plenary Session: presentation by Peter R. ODELL he will speak to this text and its accompanying illustrations as a contribution to the attempt to expose the energy supply side issues within a demand side expectation which, though modest, is well in excess of the average 0.75% growth rate of the 1990s.

The paper indicates an abundance of evidence on the basis of which a radical outcome (compared with most conventional views) can be predicated.

Introduction

Regularly recurring fears of future scarcity of energy have all proved to be groundless (McCabe, 1998; Odell, 1973; Odell and Rosing, 1983). Nevertheless, the issue of the world's potential supplies of non-renewable energies – coal, oil and natural gas remains one of concern, reflecting humankind's continuing overwhelming dependence on them for its energy needs and in the context of no better than a slow evolution of renewable energy production. This concern is, I would suggest, misplaced in the light of recent important changes on both the supply and demand sides. These changes have created the prospect for a highly sustainable energy future well into the second half of the 21st century: with sustainability being equated with the opportunity to eliminate energy-poverty not only for the estimated two to three billion of the world's present population, but also for the net additional three to four billion inhabitants of planet earth by 2050.

Demand-side Issues

Since 1973 the rate of increase in the global use of energy has, as shown in Fig.1, reverted to its long-term 1860-1945 trend of only about 2% per annum; compared with the ±5% per year growth rate which occurred from 1945-73. The probability of a future return to the latter 28 year-long much higher annual rate of growth is now close to zero, given that it reflected an inherently temporary combination of a set of energy-use conditions in all parts of the world which cannot re-occur (Odell, 1989). Thus, any contemporary realistic consideration of long-term non-renewable energy supply requirements has to be orientated to a modest growth rate in use, even without taking into account the enhanced impact on energy use of the evolving concern for CO_2 emissions and the stimulus that will give to the pace of growth in the use of renewable energies emanating from evolving technologies of direct and indirect solar energy production.

Thus, the long-term future supply prospects for fossil fuels must be put in the context of a 2% per annum growth as the highest likely requirement. Moreover, the year 2000 base from which we can now evaluate 21st century hydrocarbons' demand is very much lower than that indicated by the conventional and widely-accepted forecasts of 30 years ago. Oil production, for example, in 2000 was about 3.6 Gt compared with expectations in the early 1970s of over 19 Gt (Warman, 1972; Odell, 1973). Likewise, the cumulative use of oil since1970 has been less than 90 Gt, compared with the close to 240 Gt forecast. Indeed, use over the last three decades of the 20th century amounted to little more than the world's proven reserves as declared in 1970 (at 71 Gt). Thus, of the 157 Gt of additions to proven oil reserves since 1970 almost 138 Gt remain to be used in the 21st century. Likewise for coal and gas, for both of which reserves additions greatly exceeded demand. It is thus hardly surprising that views on the future availabilities of fossil fuels' resources and the supply potential associated with them can now be so very much more relaxed that they were in the 1970s (WOCOL, 1980).

Global Energy Production

Fig.2 shows a trend in the annual production of energy supplies by source through the 21st century – in response to energy demand growth that is sustained at 2% per annum. Non-renewable energy sources can be seen to remain dominant until 2060. Alternatives to fossil fuels do not exceed 20% of energy supplied until then, while it is 2079 before they account for 50% of supply. Even cumulatively over the century, as shown in Fig.3, renewable energy sources supply only 35% of total energy used and of this almost twothirds is supplied in the last two decades. Unless and until the governments and peoples of the world not only accept the desirability of a much faster switch to renewable energy, but also take the necessary steps to implement the change, global energy use in the 21st century will remain heavily orientated to a combination of coal, oil and natural gas. As there are, to date, no serious signs of these conditions for change being met, global energy markets can be predicated to remain dominated by non-renewable resources for decades into the future.

<u>Coal's Relative Unimportance</u>

Nevertheless, for both economic and environmental reasons, the future pattern of non-renewable energy supplies will show marked changes from the contemporary situation, while the present quite widely-presented conventional view of constrained supplies in the medium term will be seen to be based on misconceptions concerning potentially available resources (IEA, 1999). Such conventional views usually indicate coal resources as an order-of-magnitude greater than those of oil or gas and thus assume, implicitly or explicitly, that coal must become, at least, more important than oil and gas and, most likely, the dominant component in fossil fuel supplies in the 21st century (Grübler et al, 1999). However, given coal's widespread lack of acceptability for a combination of economic and environmental reasons and, even more so, as shown in Table 1, its highly geographically concentrated global patterns of both reserves (almost 53% in only 3 countries and over 90% in 10 countries) and production (54% in merely 2 countries and 91% in 10 countries), this prospect is very unlikely. The earlier expressed likelihood of coal as "the fuel of the 21st century", in the aftermath of the oil price increases of the 1970s, (WOCOL Report, 1980) has, over the past decade, been effectively undermined by a combination of local, regional and global environmental concerns over coal production and use. Instead, as shown in Fig.2, coal's share of global fossil fuel production fails to increase over the century. It makes a 21st century contribution of only just over 25% to cumulative non-renewable energy use (Fig.3).

Table 1

Global Rank Ordering of the Ten Leading Countries' Coal Reserves and Production, 1998

RESERVES			PRODUCTION		
Country	Share of Global Reserves	Cumulative Reserves' Share	Country	Share of Global Production	Cumulative Production Share
U.S.A.	25.1	25.1	China	28.0	28.0
Russia	15.9	41.0	U.S.A.	26.4	54.4
China	11.6	52.6	India	6.6	61.0
Australia	9.2	61.8	Australia	6.6	67.6
India	7.6	69.4	South Africa	5.3	72.9
Germany	6.8	76.2	Russia	4.7	77.6
South Africa	5.6	81.8	Poland	3.4	81.0
Kazakhstan	3.5	85.3	Germany	2.7	83.7
Ukraine	3.5	88.8	Canada	1.8	85.5
Poland	1.4	90.2	Ukraine	1.8	87.3
Next 20 Countries		6.6	Next 20 Countries		10.2

It is thus oil and natural gas which must, between them, continue to supply the bulk of the world's energy supply – at least until the mid-2060's. This implies an overall three-fold increase in their joint contribution to the annual supply of energy in the 21st century (see Figs. 2 and 3). The relative contributions of oil and gas to the total supply of hydrocarbons do, however, change very radically, as shown in Fig.4. As will be demonstrated later in the paper, this change is, in part, a function of possible long-term constraints on oil supplies and, in part, a reflection of the inherent advantages for natural gas in respect of both supply and use considerations. Natural gas supplies are thus indicated to continue to expand to 2090, when global production is predicated to peak at 5.5

Table 2

The changing contributions of oil to the total supply of hydrocarbons, 2000-2050 and 2100

Period	Total oil and gas supply (Gtoe)	Total oil supply (Gtoe)	Oil as a share of the total
2000	5.84	3.79	64.9
2010	6.95	4.43	63.4
2020	8.24	5.17	62.7
2030	10.58	5.76	54.4
2040	12.85	6.28	48.9
2050	14.86	6.54	44.0
↓	↓	↓	↓
2100	15.45	4.45	28.8

Table 3

The cumulative contributions of oil and natural gas to the energy supply in the 21st century

Period	Cumulative oil and gas (Gtoe)	Cumulative oil (Gtoe)	Oil's share of cumulative total (%)
Pre–2000	176	120	68.2
2000–2009	66	42	63.6
2000–2019	143	90	62.9
2000–2029	237	147	62.0
2000–2039	355	210	59.2
2000–2049	495	276	55.8
2000–2059	647	341	52.7
2000–2069	806	403	50.0
2000–2079	943	440	46.7

2000–2089	1108	493	44.5
2000–2099	1256	540	43.0

times its year 2000 level. On the other hand, as oil's output is anticipated to start slowly declining from the 2050s, its contribution to the total hydrocarbons supply ultimately falls from its present contribution of 65% to 44% by 2050 and to under 29% by 2100 (see Table 2 and Fig. 4). Over the century as a whole, its share of the cumulative use of 1256 Gtoe of hydrocarbons is, at 540 Gt, only 43% (see Table 3).

Natural Gas: the Fuel of the 21st Century

Natural gas will have overtaken coal as a global energy source by the 2020s, or even well before that if gas' substitution of oil use accelerates. Its rapidly expanding production in recent years reflects the more than doubling of proven global gas reserves since 1980 and the expansion of European and other markets for gas over the period since 1990. It thus enters the 21st century with an R/P ratio in excess of 60 years. The expansion of its production in the early decades will thus continue to be demand limited (through infrastructual or policy restraints), rather than resources-related. Indeed, the reserves of already discovered fields could in themselves serve to keep global gas production growth at 3+% per annum until 2025, location and demand permitting. But the continuation of large additional discoveries of natural gas is a certain prospect, given, first, the geographically broadening base of exploration activities and, second, the continuing opportunities for a more intensive exploitation of existing gas-rich provinces, including some hitherto thought to be well matured (eg in the Gulf of Mexico and the North Sea). The mid-point of the range of estimated additional reserves, from 197 to 303 Gtoe. indicates a volume which is about 30% greater than that of the gas used to date plus currently proven known reserves. These data, regionally defined, are set out in Table 4.

The indicated proven plus additional reserves are sufficient to support the conventional gas production curve set out in Fig.5A.

Table 4

World Gas Reserves and Resources by Region (Gtoe)

	Conventional Gas			Non-Conventional Resources	
Region	**Production to 1999**	**Remaining Proven Reserves**	**Estimated Additional Reserves**	**Coal-bed Methane, Tight Formation Gas, Gas from Shales and Gas Remaining after Conventional Production**	**Gas Hydrates and Geopressured Gas**
North America	26.9	7.5	30-52	22	6,100
Central & South America	3.0	5.6	7-22	91	4,571
Europe (excluding FSU)	7.3	4.7	5-14	36	765
Former Soviet Union	16.1	51.0	95-110	159	4,208
Middle East	3.9	44.6	28-50	99	203
Africa	2.1	9.3	5-14	29	383
Asia/Pacific (excluding FSU)	3.6	9.2	25-41	203	2,528
Total	62.9	131.9	197–303	837	18,758

Source: H-H Rogner, An Assessment of World Hydrocarbon Resources, IIASA,1996.
BP Amoco: Statistical Review of World Energy, 1999. Author's estimate of cumulative production to 1999.

Superimposed on the 200 years' curve of conventional gas supply shown in Fig.5B is the complementary production curve for non-conventional natural gas. The production of the latter assumed to begin in 2020, with the shape of the curve emerging from the depletion of some 650 Gtoe of the estimated ultimately recoverable reserves of 837 Gtoe, as shown in Table 4. These reserves emerge from the combined potential availability of gas from coal-bed methane, tight formation gas, gas from fractured shales and gas remaining in place after conventional production. It excludes, however, the possibilities of any recovery at all of methane from gas hydrates, the energy value of which is tentatively estimated to be up to 10 times greater than all other hydrocarbon resources taken together (H.A. Rogner, 1996). Even without taking any of this potential from gas hydrates into account, non-conventional gas production starting in the 2020s seems likely to become the more important component in global total gas supply within 50 years and, thereafter, its production can continue to grow beyond the end of the 21st century. Natural gas overall in 2100 is predicated to supply over 50% of the year's non-renewable energy production (see Fig.2) while, over the 21st century as a whole, it supplies about 41% of the cumulative total of non-renewable energy (see Fig.3).

Gas will thus undoubtedly be the fuel of the 21st century (as coal was of the 19th and oil of the 20th), even within the framework of the limiting assumptions on gas resources' exploitation as specified above (viz. the exploitation of only 75% of ultimately recoverable non-conventional gas and no gas at all from gas hydrates). These limitations do, indeed, inhibit the ability of gas supply to grow sufficiently post-2050 so as to sustain a 2% per annum expansion in overall non-renewable energy use. This predicated annual "shortfall" in the supply of non-renewable energy rises from about 4.5 Gtoe in 2060 to almost 25 Gtoe in 2100. As can be seen in Fig.2, this would necessitate a rapidly rising supply of alternative energies during the last quarter of the 21st century. There seems likely by then, however, to be a better than 50% probability that additional gas supplies from the initial exploitation of gas from hydrates will become available. Sixty more years of continuing scientific advances and engineering capabilities would seem to provide time enough to enable a small part of that massive potential source of energy in the form of the world's preferred fossil fuel for both commercial and environmental reasons, to be brought to the market. Such a development could take care of the "shortfall", assuming, of course, that the exploitation of gas hydrates is then able to compete in economic terms with the alternatives of renewable energies and that it is, moreover, not excluded from development by global warming considerations.

Oil's Relative Decline in Importance

The future for oil lies squeezed – to a greater or lesser extent, depending on environmental and economic considerations – between the prospective solidity of 2.3 to 6 Gtoe of annual global coal supply, on the one hand, and the dynamics of the 21^{st} century gas industry, on the other. Oil's future thus seems likely to become demand-side limited, so that potential supply-side (= resources) limitations represent only a low probability prospect. This is shown in Fig.6A in which the production curves indicate most of the 200 years' period of actual and potential oil supply from 1940-2140. Conventional oil production is, of course, already well into its life cycle, but nevertheless, it still has ±30 years to go to reach its annual output zenith at ±4.36 Gt in the early 2030s (compared with 3.3 Gt in 2000), when about 240 Gt of such oil will have been used. Thereafter, the eventual depletion of the remainder of the presently estimated ultimately recoverable reserves (URR) of conventional oil of 410 Gtoe (= 3005×10^9 barrels) will take another century. This figure of conventional oil's URR is close to the year 2000 value of the calculated upward trend, based on 33 estimates over the past 50 years (see Krylov et al, 1997), of the conventional oil resource base as presented to the 1997 World Petroleum Congress. It is also very close to the mid-point of Shell's 1995 presentation of an estimated 2675 to 3275 billion barrels range for ultimately recoverable conventional oil (Shell, 1995) and to that of the most recent USGS estimate of the URR at 3003 billion barrels (USGS, 2000). These data (except for that of the USGS) are shown in Fig.7.

By contrast, non-conventional oil production has barely started. It is now being developed more rapidly especially in Western Canada, but, even so, when using a conservative assumption of only 3000x10^9 barrels of ultimately recoverable reserves (within a resource base many times larger), it will, under restraints imposed by costs, environmental and demand considerations, still take 80-90 years to reach its potential peak production (see Fig.6A) at a level which seems likely to be a little lower than that reached by conventional oil in the 2030s. As in the case of conventional and non-conventional gas, however, the two types of oil, though designated by the nature of their occurrence, are essentially complementary in respect of satisfying market demand. Customers are indifferent as to the sources of the crude oil from which their demands for products are derived; their interests lie only in the utility to them of the oil products they buy. Thus, Figure 6B shows the production of both types of oil in an integrated way. From 2000-2030 non-conventional oil accounts for only about 12% of total oil supply, so that it merely modestly supplements increasing availabilities of conventional oil. Thereafter, its relative importance in total supply rises sharply. So much so, indeed, that by 2060 it becomes the more important component in oil supply overall. By 2100 non-conventional oil is predicated to be over 90% of the total. The near-100 year period suggested for the full change from conventional to non-conventional oil can be interpreted as reflecting a slow, but continuing, process based on the joint influences of economic considerations and technological developments.

The oil component in the 21st century's energy production potential is, however, by no means a small or short-lived one. The supply increase shown for the first half of the century is at a rate made possible by the depletion of already known reserves, of ongoing reserves appreciations and of continuing new discoveries of conventional oil, plus the steadily rising flows of non-conventional oil (Fig.8). The designated peak of production in about 2060 can, however, be interpreted as being both later and lower than it would otherwise have been in the absence of competition from other energy sources. As a consequence of the latters' increasingly competitive position vis à vis oil in the first half of the 21st century, the subsequent decline rate in oil supply after 2060 will be relatively slow. Thus, even in 2100, as shown in Fig.6, there could well still be an oil industry which is larger than that of 2000! By then, however, in the context of potential resources' limitations and the intensifying competition from other energy sources, oil will contribute, as shown in Fig.2, rather less than coal to global energy supply: while it will, of course, have long-since become less important than natural gas (see Fig.4). In these contexts whilst oil's geo-political importance will undoubtedly continue into the early decades of the 21st century, it will, thereafter, become merely another energy source of steadily decreasing importance in meeting the world's energy demand: and it will, moreover, be one which is available from a broader geographical diversity of locations than has been the case to date. The progress of such diversification of supply will be a function of the oil price (see below) and of concerns for supply security (Odell, 1992 and 1997).

Trends in Production Costs: and Prices

In this paper implicit references have been made to trends in costs and prices, but these observations do need to be brought together into an integrated overview as questions of production costs and of returns on investment constitute a central set of parameters in resource evaluations. No significant differences can emerge in the context of competitive markets between the alternative resources – or between regions – except as temporary phenomena. When such divergences do emerge they inevitably lead either to compensating changes in supply schedules, so that the equilibrium is re-established, or to the need for subsidies or other protective measure to sustain expensive production. Contrasting transportation costs in getting production to markets (as, for example, between oil and gas) produce contrasting netbacks for different fuels in the same regions and between regions for the same fuel, but in a macro-study of the overall global situation over a long period of time, these contrasts seem unlikely to amount to much more than fine-tuning elements in the global energy system.

The starting point of this long-term study of the future availability of coal, oil and natural gas is the declaration of proven reserves for each fuel. Such declarations are, by definition, of reserves that are economic to produce at current levels of costs and prices. As the total quantity of the reserves declared remains much more than adequate to serve the world's slowly expanding energy markets, then competition will generally keep prices from escalating in real terms. Of course, in past decades traumatic events, such as US oil import quotas in the 1960s and 1970s and supply limitations imposed by OPEC and others in the 1970s, 1980s and over the past two years, have upset the equilibrium from time to time. Similar relatively short-term influences on oil prices will undoubtedly occur in the future, but, given their essentially ephemeral nature, they are irrelevant to an attempt to predict overall long-term cost and price trends.

The potential supply schedule forecast for oil – for long the price leader in the fossil fuel market – suggests little or no pressure of demand on supply for at least the next 20 years. For this period there is thus no reason why oil prices in real terms should rise much and no reason why any significant volumes of reserves of oil, gas or coal which involve higher costs should be produced. The inter-quartile average annual price range of $16.85 to $19.50 per barrel (measured in terms of 1999 dollars) for internationally traded crude oil over the past 15 years seems to indicate the most likely price-range for oil for the medium-term future (in the absence of traumatic events as defined above). Technological developments have already brought production costs down in many areas of production (Econ Centre for Economic Analysis, 1997) and this process can be expected to continue.

Sometime in the 2010s, however, upward price pressure on the oil market seems likely as the attempt to maintain growth in the production of conventional oil leads to a requirement for higher investment costs. An increase of 10-20% in unit exploration and development costs will then be sustained by the required new and heavy investments in the first substantial exploitation of non-conventional oil. Such cost increases will need to be passed through into the general level of prices. The equilibrating price of $17-20/bbl of oil in the meantime thus seems likely to be converted by 2020 to $19-24/bbl (in 1999 dollars). At this higher real price level, the requirement for the highest cost oil producer to be able profitably to sell into the market will be satisfied. Neither gas nor coal seem likely to ‘need’ the price increase, but the producers will accept it as a means for enhancing their rate of return on investment. In the case of coal, such price rises could enable the industry to absorb the relatively higher carbon taxes to which coal by then seems certain to have become subject. Equilibrium in the global energy market will thus be maintained in a situation in which alternative energies will, in general, still require a subsidy and thus be unable to bring downward pressure to bear on prices (World Energy Council, 1997).

The next likely future non-renewable energies price crunch, when upward pressures generated by relative scarcity again exceed the downward pressures engendered by technological advances, will emerge as conventional gas output approaches its period of maximum production in the 2040s. By then gas will have overtaken oil as the world’s single most important source of energy and will thus also have become the price leader in the global energy market. In order to sustain the growth of the industry into a period in which the profitable exploitation of non-conventional gas is assured, a further modest price increase (in real terms) will then be required in order to generate the higher level of investments involved in exploiting such gas. This could take the oil equivalent price to a level of $21-26/bbl (in 1999 dollars).

By that time, however, yet higher taxes on the use of coal for environmental reasons will be tending to price the fuel out of many geographically disparate markets. Technological improvements in coal production notwithstanding, coal will not have the ability generally to influence energy prices, although it may still exercise downward pressures on energy prices in a limited number of coal-rich and coal-dependent countries. Oil will also have become largely a price taker – rather than a price maker – so that the industry will be able to benefit from the additional revenue flows generated from the upward movement of gas prices. This will engender sufficient returns for financing investments in the continuing expansion of non-conventional oil production to 2080 (see Fig.6A). Likewise, a rapidly expanding delivery of renewable energies to the market will be made possible from the upward price movements in the market. These will enable governments to reduce or even eliminate the subsidies hitherto required for sustaining the growth of renewable energy production.

From 2040 to 2060, as the supply of fossil fuels becomes increasingly orientated towards natural gas, global energy supply seems likely to enter the age in which gas supply and users' technologies are honed towards 'perfection', so that costs do not rise in real terms. Gas prices also seem likely to be stabilised by the sharpening competition created by the lower real costs of delivering renewable energy supplies under conditions of increasing economies of scale.

This paper has suggested that increases in the supply of gas post-2060 may fail to reach the level required to sustain an annual growth of 2% in the supply of non-renewable fuels. Cost increases required to maintain gas production at the high global level then achieved may become a problem, with particular respect to the exploitation of gas hydrates.

Whether or not such cost increases will become significant before 2100 is impossible to judge. Even if they do, there is, however, no certainty that they could be passed on in higher prices as the improving economies and technology of energy supplied by renewable energies could by then be setting the general price level. Nor is it impossible that the very large resources of relatively low cost coal remaining in 2100 may finally become a replacement fuel. This could result either from the failure of global warming to occur (so that CO_2 emissions are no longer considered a problem), or from the emergence of technologies which enables coal to be used in a way which is environmentally friendly (Williams, 1998).

Indeed, by the end of the century in the context of continuing technological progress, a fall in the real costs of supplying renewable energy seems more likely than a situation of inherently rising costs. If so, then this will bring downward pressure to bear on the prices indicated above for non-renewable fuels. Such a development could, conceivably accelerate the latters' already declining contribution to world energy supply, as they become unable to compete effectively in the market-place.

Are Oil and Gas Fossil Fuels?

Finally, a word of caution is necessary on the essential fragility of a study on the very long-term future for the world's energy supply which accepts without question the validity of the original 18th century hypothesis that all oil and gas resources have been generated from biological matter in the chemical and thermodynamic environments of the earth's crust. There is an alternative theory – already 50 years old – which suggests an inorganic origin for additional oil and gas (Porfir'yev, 1974; Kenney, 1996; Gold, 1999). This alternative view is widely accepted in the countries of the former Soviet Union where, it is claimed, "large volumes of hydrocarbons are being produced from the pre-Cambrian crystalline basement" (Krayushkin et al, 1994). Recent applications of the inorganic theory have, however, also led to claims for the possibility of the Middle East fields being able to produce oil "forever" (Mahmoud and Beck, 1996) and to the concept of repleting oil and gas fields in the Gulf of Mexico (Gurney, 1997). More generally, it is argued, "all giant fields are most logically explained by inorganic theory because simple calculations of potential hydrocarbon contents in sediments shows that organic materials are too few to supply the volumes of petroleum involved." (Porfir'yev, 1974).

The potential significance of the alternative theory of the origin of additional oil and gas potential is self-evident with respect to the issues of the longevity of hydrocarbons' production prospects and to production costs in the 21st century. Instead of having to consider a stock reserve already accumulated in a finite number of so-called oil and gas plays, the possibility emerges of evaluating hydrocarbons as essentially renewable resources in the context of whatever demand developments may emerge. If fields do replete because the oil and gas extracted from them is abyssal and abiotic (based on chemical reactions under specific thermodynamic conditions deep in the earth's mantle), then extraction costs should not rise over time as production from such fields can continue for an indefinite period. Neither do estimates of reserves, reserves-to-production ratios and annual rates of discovery and additions to reserves have any of the importance correctly attributed to them in evaluating the future supply prospects under the organic theory of oil and gas' derivation (Campbell, 1997). In essence, the "ball park" in which consideration of the issues relating to the very long-term future of oil and gas has hitherto been made would no longer remain relevant.

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Fig 1. Trends in the Evolution of World Energy Use (1860 - 1997)

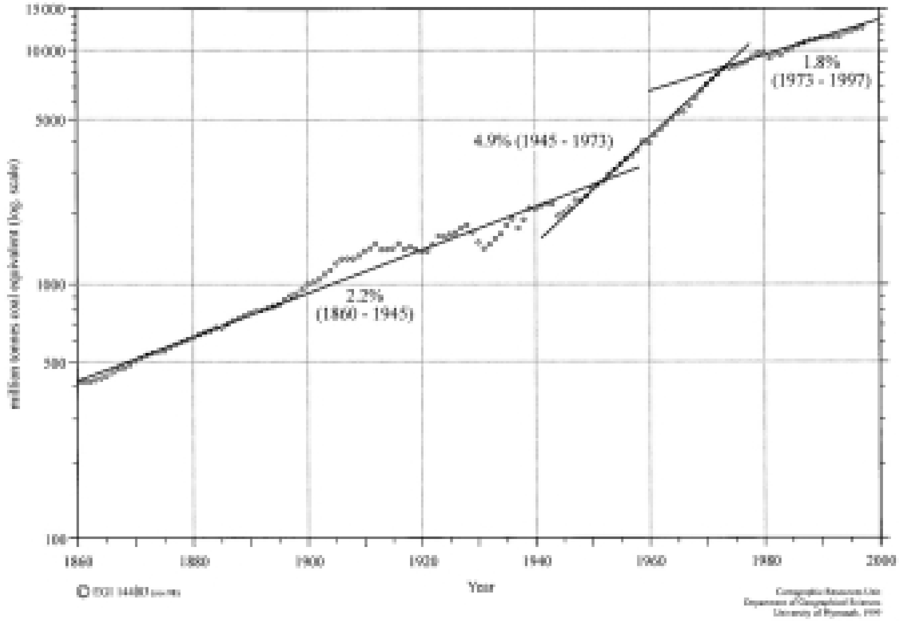
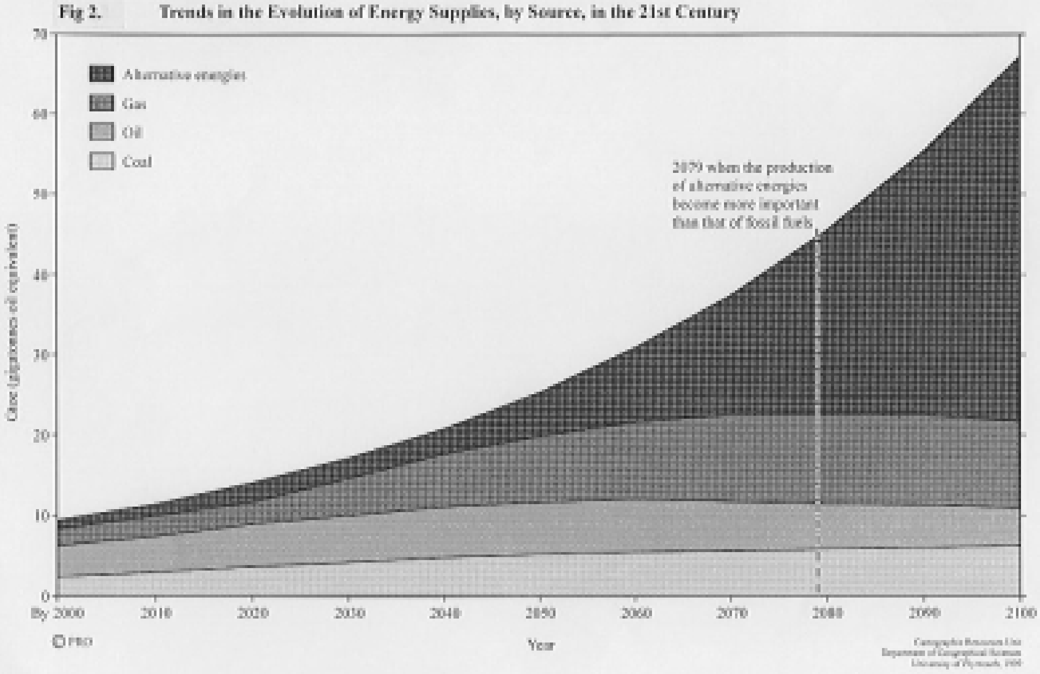


Fig 2. Trends in the Evolution of Energy Supplies, by Source, in the 21st Century



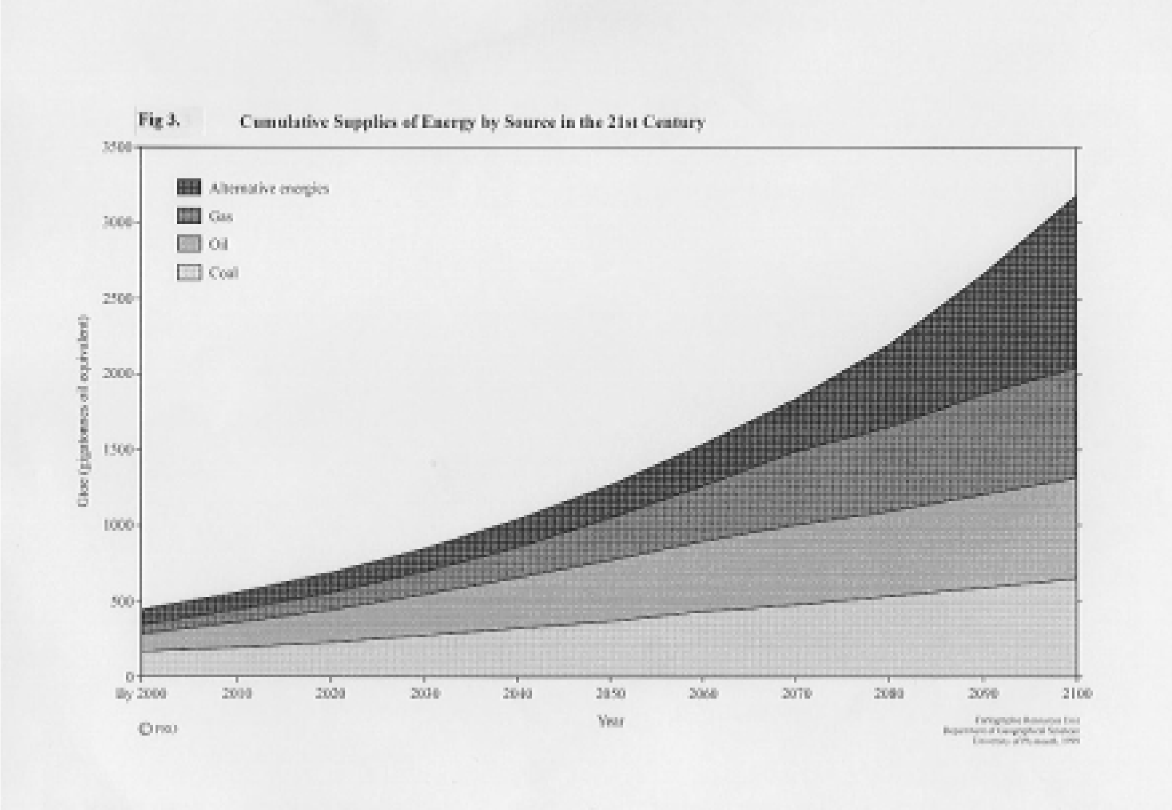


Fig 3.
Cumulative Supplies of Energy by Source in the 21st Century
Alternative energies
Gas
Oil
Coal
Gtoe (gigatonnes oil equivalent)
3500
3000
2500
2000
1500
1000
500
0
By 2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year
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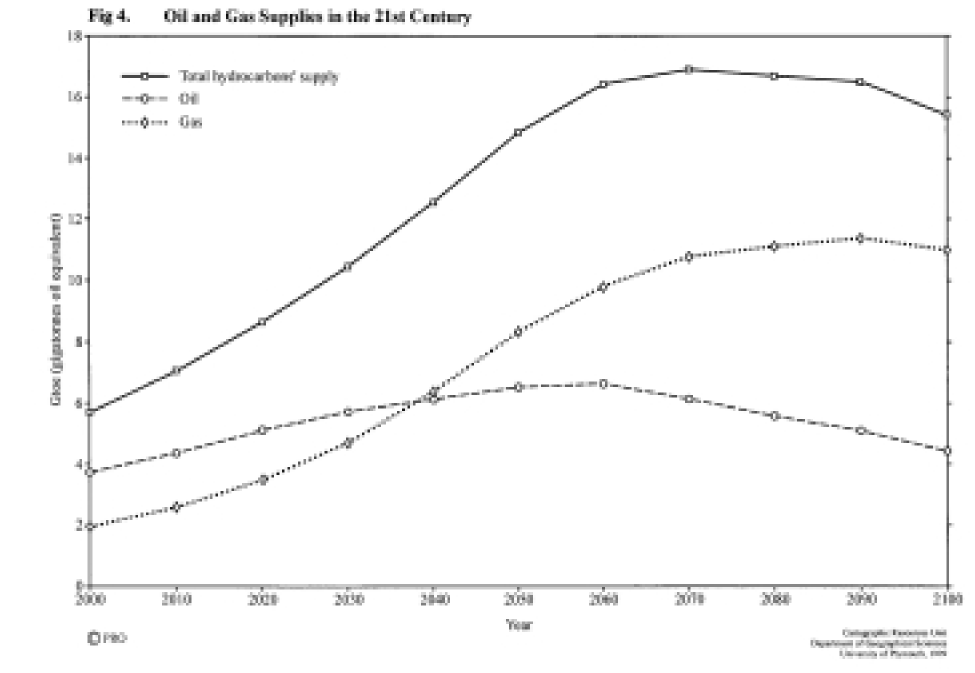
Fig 4.
Oil and Gas Supplies in the 21st Century
'Total hydrocarbons' supply
Oil
Gas
Gtoe (gigatonnes oil equivalent)
18
16
14
12
10
8
6
4
2
0
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year
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Fig 5A. Production of Conventional and Non-Conventional Gas Production, 1940 - 2140

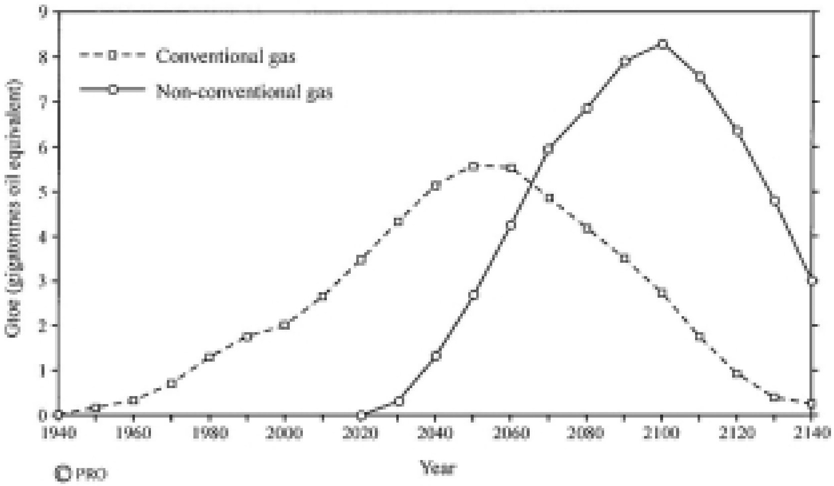

Fig 5B. The Complementarity of Conventional and Non-Conventional Gas Production: giving a Higher and Later Peak to Global Gas Supplies

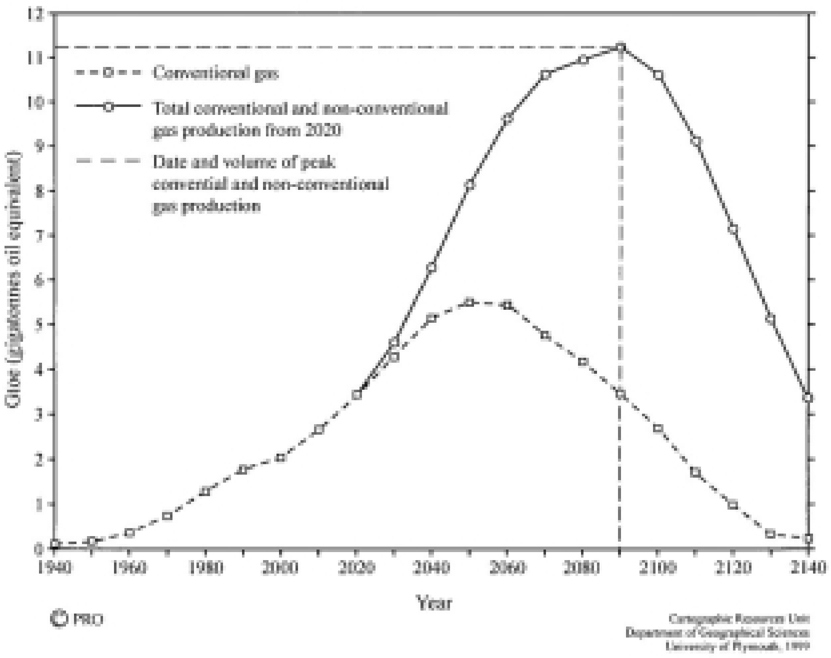

Fig 6A. Production Curves for Conventional and Non-Conventional Oil, 1940-2140

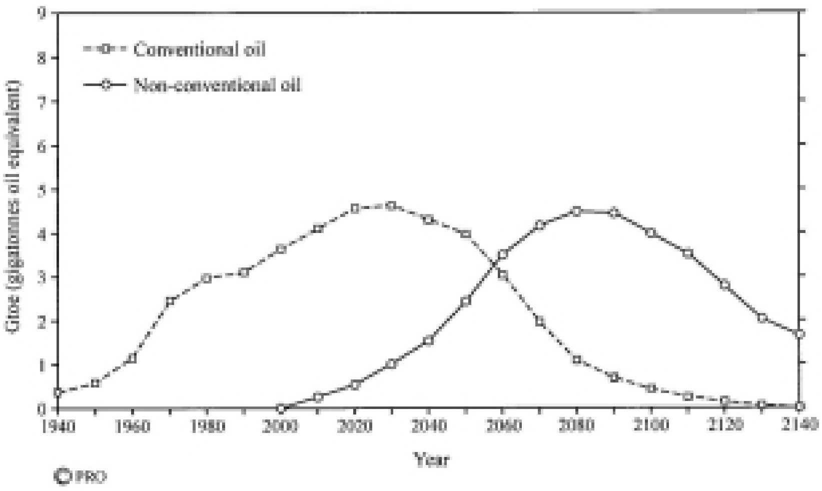

Fig 6B. The Complementarity of Conventional and Non-Conventional Oil Production: giving a Higher and Later Peak to Global Oil Supplies

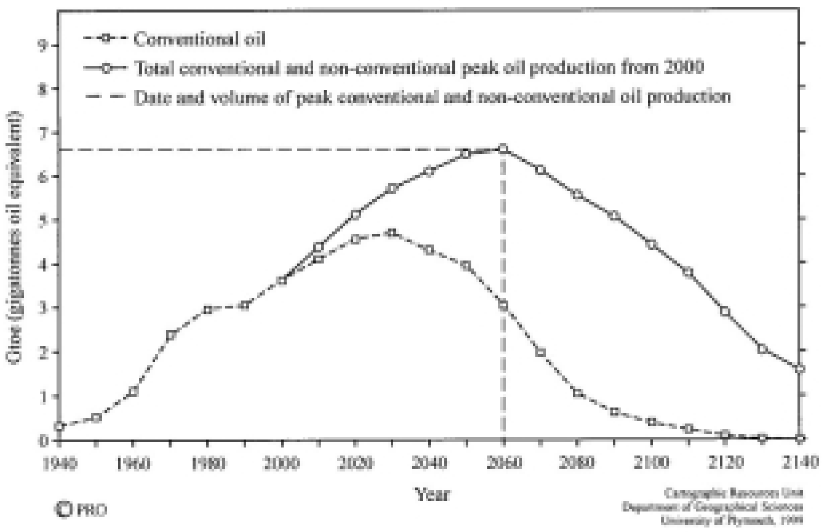

Fig 7. Assessments of Total World Initial Oil Reserves over Time

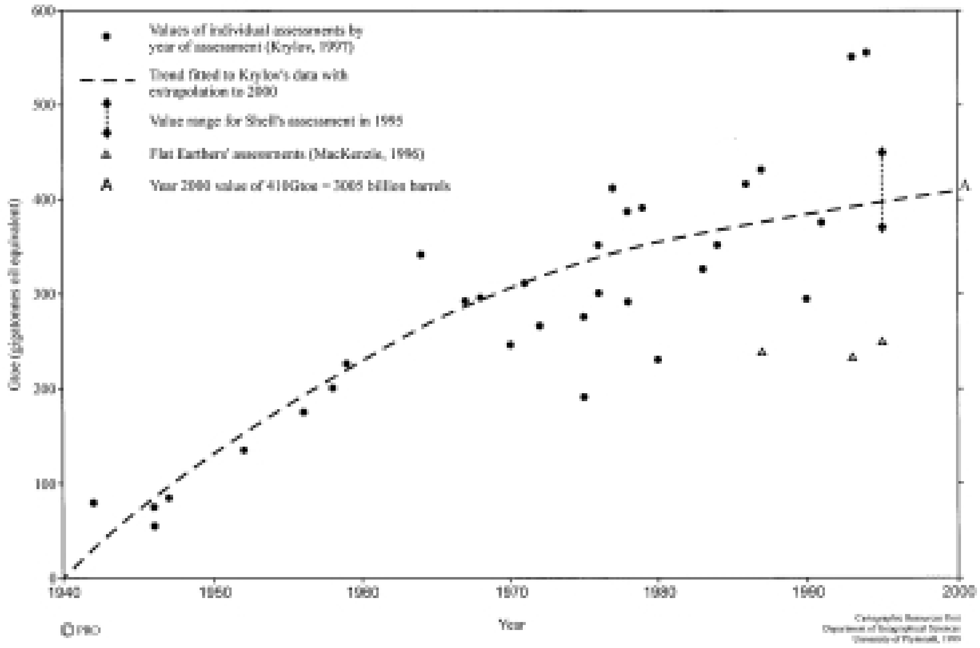

Fig 8. The Appreciation of Proven Reserves of Conventional Oil 1945-2020